APPENDIX D - "Chesapeake Bay Shoreline Study: City of Norfolk, Virginia"

Prepared By: Dr. David Basco, Beach Consultants, Inc.
January 2004

Chesapeake Bay Shoreline Study:
City of Norfolk, Virginia

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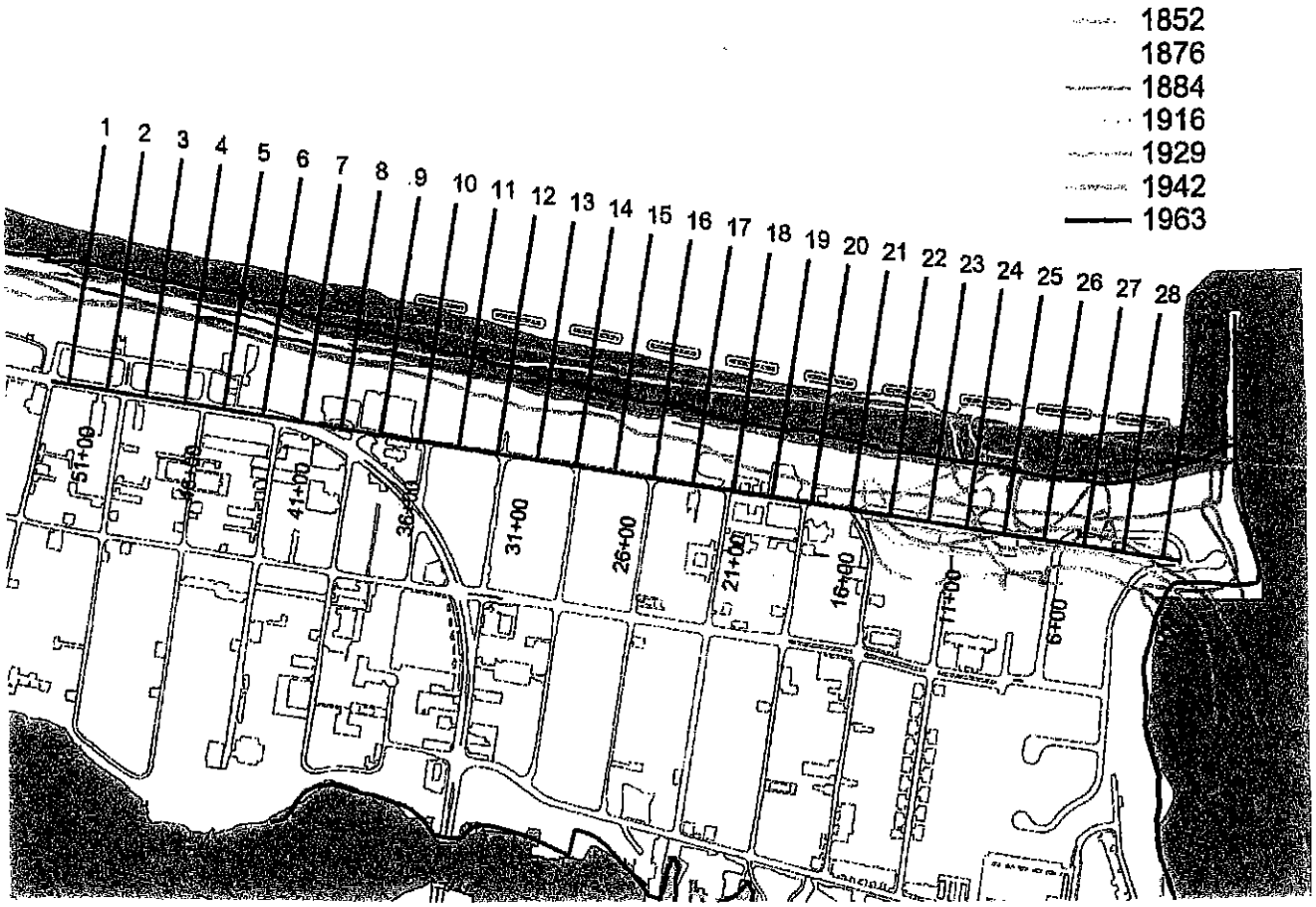

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Chesapeake Bay Shoreline Study
City of Norfolk, Virginia

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Executive Summary

Historic positions and change rates of the mean high water shoreline (MHWL) for the Chesapeake Bay region of the City of Norfolk, Virginia have been determined for the years 1852, 1876, 1884, 1916, 1929, 1942, and 1963. The primary data source was the NOAA, National Ocean Survey (NOS), National Archives. Shoreline map position data was digitized in Virginia, State Plane Coordinates (South Zone) referenced to NAD 83 expressed in "United States" feet units compatible with City of Norfolk survey data. A reference Baseline was established that essentially follows the center of Ocean View Avenue so that all shoreline distances are seaward and positive. When plotted together in AutoCADD 2000, the distance from the Baseline to the mean high water shorelines, and relative shoreline change rates in time can be quantified for locations of interest.

A secondary and more recent data source are the aerial photographs for 1937, 1956, 1970, 1976, and 1980 from the Virginia Institute of Marine Science (VIMS). Estimates of the high water marks were made and the same procedures used to quantify shoreline positions and change rates. Aerial photos from 1995, 1999, and 2002 were also used to quantify positions.

For the 65-year interval (1852-1916) the entire shoreline was stable to slightly accretionary. Jetty construction to fix the location of Little Creek Inlet in 1926-28 significantly interrupted the natural, sediment transport processes, and cased major erosion problems on Norfolk's beaches that continue to be felt today.

Groin fields constructed in the 1920's and 1930's; beach nourishments beginning in 1953; and the construction of the terminal groin and nearshore breakwaters in the 1990's and 2000's have all helped to mitigate the erosion problem created by the jetties. Shoreline positions and change rates are all influenced locally and over distance by (1) these coastal works, (2) the dates of the data, (3) the methods to acquire the data, and (4) the time intervals to estimate the rates. Detailed shoreline position data as summarized in the tables, graphs, and on the CD-ROM (Appendix) will be useful to calibrate numerical models that calculate shoreline change. These models can then be applied for future plans to manage the City's beaches.

A number of recommendations are included. Existing beach profile data should be archived and the routine collection of beach profiles should be initiated to determine storm, seasonal, and annual variations of sand volumes on the beach. The beach is an important resource for storm damage mitigation of upland structures and infrastructure, recreation, and the environment. Knowledge of total, sand volume changes over time is needed to effectively manage the beach.

Acknowledgements

We wish to acknowledge and thank the following individuals who helped on this project. Aerial photographs and construction dates for Little Creek Inlet jetties were provided by Scott Hardway of VIMS. Cyndy at Do-You-Graphics, Woodbine,MD helped to obtain the historic map data on CD-ROM. Jim White, P.E. coastal engineer, City of Norfolk helped to determine dates for groin construction and beach nourishment projects.

The Project was directed by Johnny Martin, P.E. with help from Laurel Krynock, Raleigh Office and Michael Crist, Norfolk Office, Moffatt and Nichol Engineers.

All the data takeoff for shoreline positions, the calculations and graphical materials were ably conducted by Takashi Okamoto. We gratefully acknowledge his tremendous efforts. Julie did her usual professional job in typing this report.

All the errors and omissions are solely due to the primary author.

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Section 1.0
Introduction

1.1 Background

The City of Norfolk, Virginia continues to study, design, and construct coastal engineering works (nearshore breakwaters, beach nourishments, and dunes) for storm damage mitigation and enhancement for upland property redevelopment. To aid these efforts, Moffatt and Nichol Engineers, Norfolk,VA have been retained as the Coastal Engineering consulting firm for the City. The region of concern is the Chesapeake Bay shoreline from the property boundary at the jetties of Little Creek Inlet to the western tip of Willoughby Spit (Figure 1). Of interest herein is documentation of the historic, mean high water (MHW) shoreline position for this region dating back in time to the earliest map and photographic data. Shoreline change rates before and after coastal engineering works (jetties, dredging, groins, beach nourishments, seawalls/bulkheads) are the final products of this work.

Beach Consultants, Inc., Norfolk was contracted (August 12, 2003) by Moffatt and Nichol Engineers to perform all necessary work tasks to quantify shoreline positions in time and shoreline change rates for the study region.

Section 2 presents the data sources and briefly summarizes the coastal engineering works. Details for horizontal control, the Baseline location, and vertical datum to define the MHW shoreline positions are presented in Section 3. Then, in Section 4, we present the final results from map data for the years 1852, 1876, 1884, 1916, 1929, 1942, and 1963. This map data does not cover the entire 38,000 ft long shoreline of interest. Photographic data are available after 1937 and are influenced by many coastal engineering works so are summarized separately in Section 5. The discussion in Section 6 focuses on the shoreline prior to Little Creek Inlet jetty construction and the consequences afterwards. All the data is summarized in Section 7 along with our conclusions and recommendations for this effort. The Appendix contains a CD with all the data.

1.2 Study Sections

In 1993, the City published a Beach Management Plan (Andrews, Miller and Associates, 1993) for the Chesapeake Bay shoreline shown in Figure 1 that employed the names Willoughby Spit (western end) and East Ocean View (eastern end). Three critical erosion/potential storm damage areas and three non-critical areas were identified using street names as boundaries. Table 1 summarizes these six areas along with a key, physical name for that reach. These region names will be used to define the study sections throughout this report.

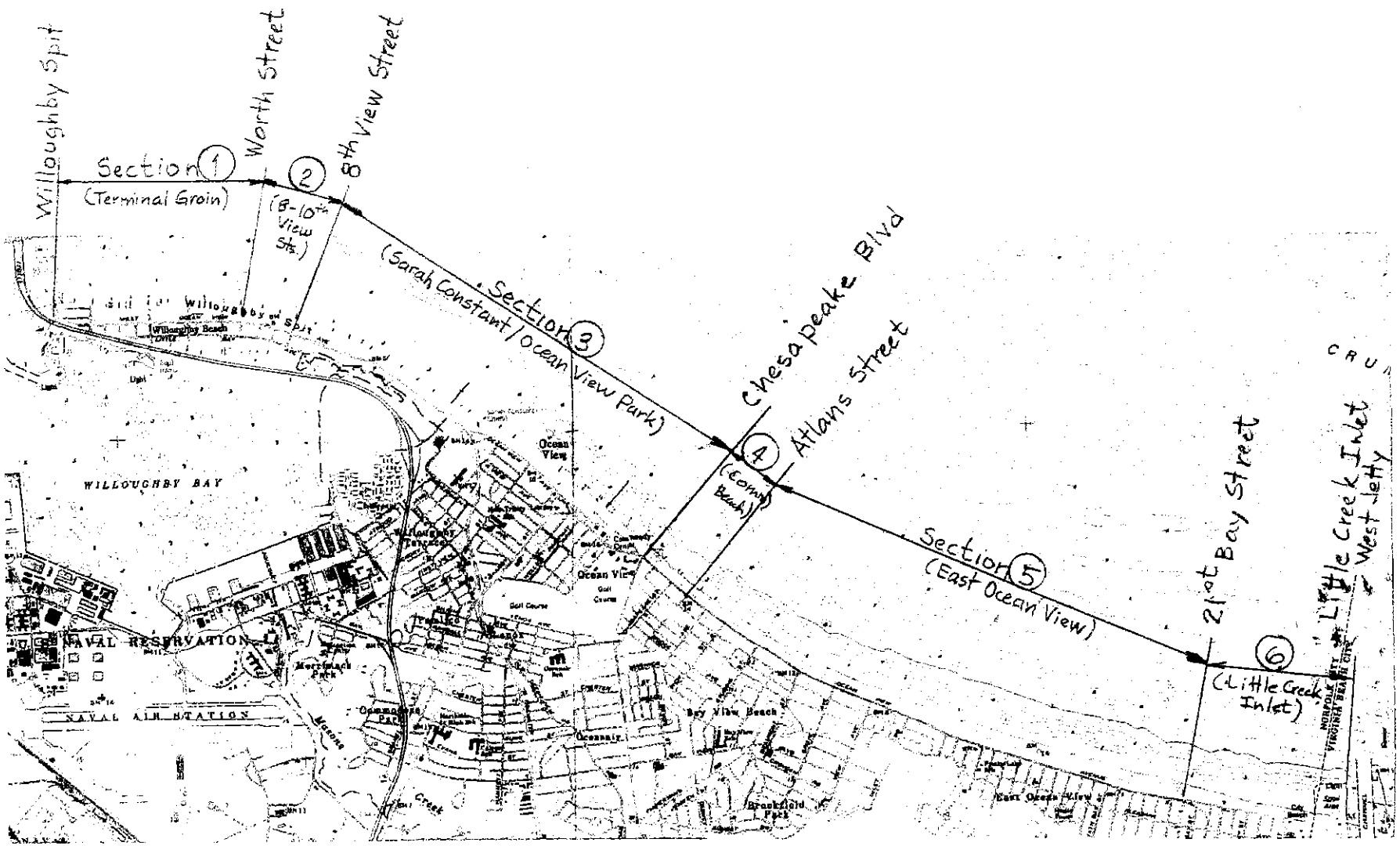


Figure 1 Location map for study of shoreline movements between the western jetty of Little Creek Inlet (east) and the end of Willoughby Spit (west) for Chesapeake Bay, City of Norfolk, Virginia(from U.S. Geological Survey, quadrangle maps)

Table 1 Study section locations, names, and lengths

Section No.	Location*		Status	Name	Section Lengths	
	From	To			feet	miles
1	Tip Willoughby Spit	Worth Street	Non-critical	Terminal Groin	5063	0.959
2	Worth Street	8th View Street	Critical	8-10th View Street	2272	0.430
3	8th View Street	Chesapeake Blvd	Non-critical	SarahConstant/Ocean View Park	10434	1.976
4	Chesapeake Blvd	Atlans Street	Critical	Community Beach/ Central Ocean View	1573	0.298
5	Atlans Street	21st Bay Street	Non-critical	East Ocean View	14865	2.815
6	21st Bay Street	Little Creek Inlet	Critical	Little Creek Inlet	3882	0.735

*As identified in the Beach Management Plan, City of Norfolk, 1993

The lengths of these sections are tied to the Baseline Stations in Section 3 and schematically depicted in Figure 1.

1.3 Scope of Work

Work reported herein took place between July 1 and December 31, 2003. The major time constraint was tracking down, ordering and obtaining the NOAA/NOS "T-sheets" from the National Archives at College Park, Maryland. Data take-off from this map data and from the aerial photographs provided by the Virginia Institute of Marine Science (VIMS) was also intensive. Analysis was divided into two Phases, with Phase I focusing on the Little Creek Inlet section and preliminary results (data only) provided on August 9, 2003.

No new aerial photographs were made for this study and it did not include a search for, organization, and archiving any beach profile data available at VIMS or from the City of Norfolk. Detailed inventory and cataloging of all coastal strictures (jetties, groins, outfalls, seawall/bulkheads, artificial dunes, etc.) was also not part of the Scope of Work.

Section 2
Historic Maps, Photographs, and Engineering Works

2.1 Map Data

2.1.1 NOAA/NOS-CERC Study

The primary source of accurate, historic, shoreline map data found in Everts et al. (1983) for the southeastern corner of Virginia's oceanfront and the Chesapeake Bay unfortunately did not include the City of Norfolk shoreline in Figure 1. Consequently, the historic, reference, "T-sheet" data was obtained for this study, as discussed below.

2.1.2 National Archived "T-Sheets"

Topographic surveys of the land above water have been compiled by the National Ocean Service (NOS) of NOAA since the early 1800's and include shorelines. They are commonly referred to as "T-sheets" for the topography as opposed to bathymetric charts, which focus on the underwater elevations (bathymetry) for navigation.

Table 2 summarizes the available, historic "T-sheets" for shoreline data for the southern part, Chesapeake Bay, as applied for this study. The company, Do You Graphics, Woodbine, MD provided the additional "T-Charts" as .tif files on CD-ROM.

Table 2 Summary of available historic "T-sheets" of shoreline data Chesapeake Bay, Southern part (MD-VA-NC)

Topographic Index No.	T-Sheet Number	T-Sheet Date	T-Sheet Scale	Remarks (Coverage)
11A	T-507	1852	20,000	Partial
11B	T-1462a	1876	20,000	Partial
11C	T-1659	1884	20,000	Partial
11D	T-3647	1916	30,000	Full
11E	T-4456	1929	10,000	Partial
134-E-F	T-8301,02	1942	20,000	Partial
----	T-11704	1963	20,000	Full

Shoreline position data was obtained for the entire region for 1916 and 1963 and only parts of the region for the remaining years 1852, 1876, 1884, 1929, and 1942 as shown in Section 4

2.2 Aerial Photographic Data

Historic, aerial photographs of the region were obtained from the VIMS as provided to Moffatt and Nichol, Engineers. Photographs for 1937, 1956, 1970, 1976 and 1980 came

on a CD-ROM in .tif format. Hard copy photos for 1995, 1999, and 2002 came in large file folders. Again, for some years, only partial coverage was provided.

2.3 Coastal Engineering Works

2.3.1 Little Creek Inlet Jetties

The earliest coastal engineering works were the jetties at Little Creek Inlet. The east jetty was started in December 1926 and finished in January 1928. In November 1928 the west jetty was completed (Hardaway, 2003, personal communication; see also Das, 1974). Figure 2 displays MHW shoreline positions plotted from the "T-sheet" data (Table 2) for 1852 (red), 1876 (yellow), 1884 (green), and 1916 (light blue) *before* the jetties were built. Immediately after construction, shoreline positions westward were drastically changed as discussed in Section 4. Inlet jetties are not shown in the City's AutoCADD drawing.

2.3.2 Groin Fields

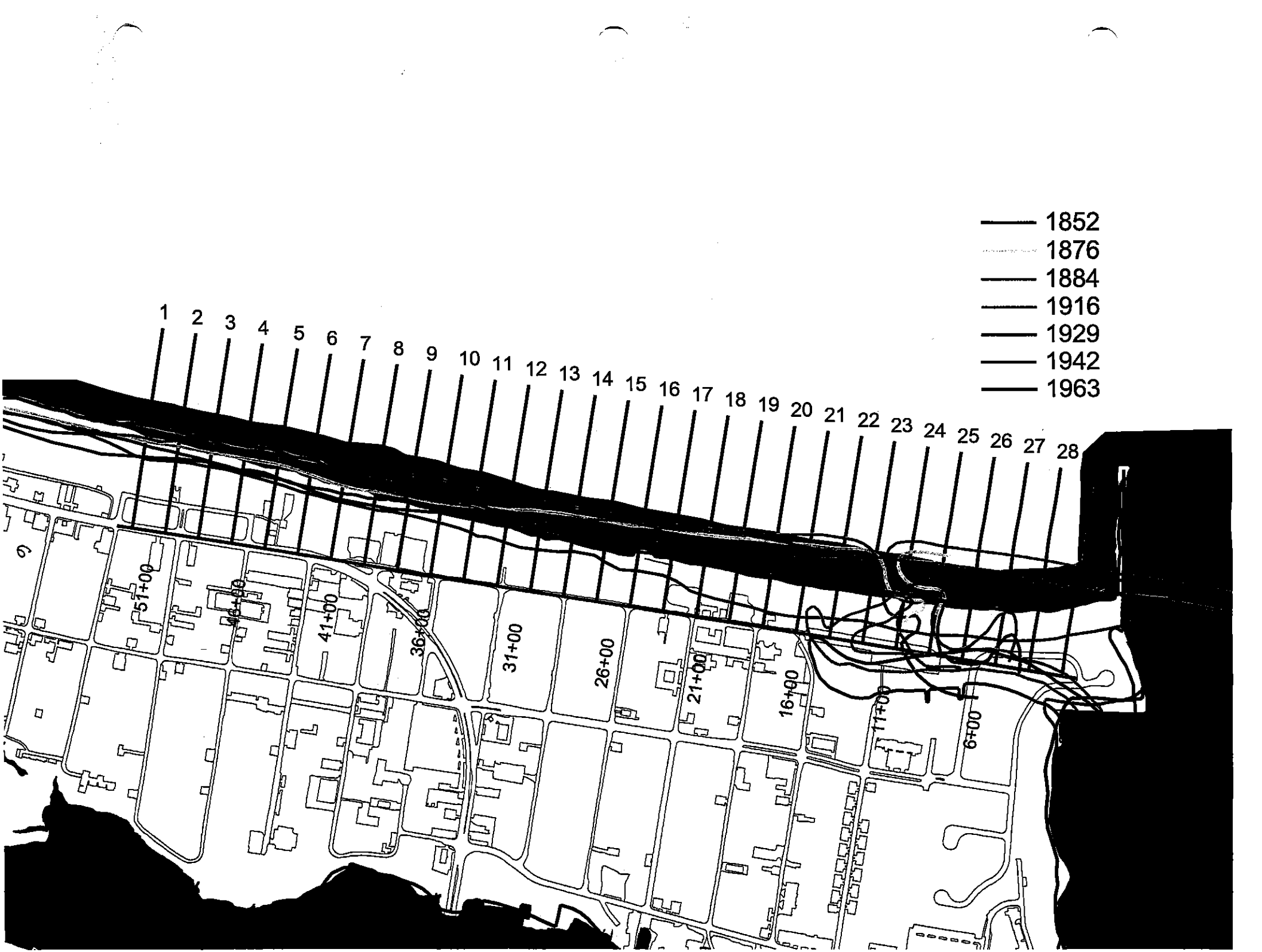
Beginning in the 1920's to 1937, private property owners built 62 groins along the Willoughby Spit shoreline (Ludwick, 1987). Figure 3 has been adapted from the Beach Management Plan (Andrews, Miller, and Associates, 1993) and displays the location of the 37 timber, sheet-pile groins constructed by the City of Norfolk between Willoughby Spit and Chesapeake Boulevard starting in September 1938 (White, 2003, personal communication). Typical groin lengths were 260-330 feet, spaced about 500 feet apart. Three of the five easternmost groins were removed in 1983 and five groins reconstructed on the western end of Willoughby Spit by the City (Andrews, Miller and Associates, 1993). Today's groin field is not shown on the City's AutoCADD drawings.

2.3.3 Nearshore Breakwaters and Terminal Groin

Two nearshore breakwaters and the terminal groin on the far western end of Willoughby Spit were constructed in 1990. The original, wooden groin was raised and extended using natural rock and rock also employed to construct the rubble-mound breakwaters. The main purpose was to eliminate the transport of sand past the original terminal groin. The crest elevation of the terminal groin was modified in March 1997. Approximately 200 ft of the landward trunk was raised to +7 ft NAVD '88.

Seven, nearshore, rubble-mound breakwaters were constructed in Section 2, "8th-10th View Streets" in April 1997 (bw 1-4) and March 1998 (bw 5-7) with construction from west to east (White, 2003). Additional work on bw 7 took place in December 1999 (spur) and March 2002 (toe extensions). See the Beach Management Plan (Andrews, Miller and Associates, 1993) for further details. Typical lengths are 200 feet, with spacing about 400 feet on centers so the gap distance is also 200 feet.

Four, nearshore rubble-mound breakwaters were constructed in Section 4, just east of "Community Beach," in 1999. The 1993 Beach Management Plan called for five


1852
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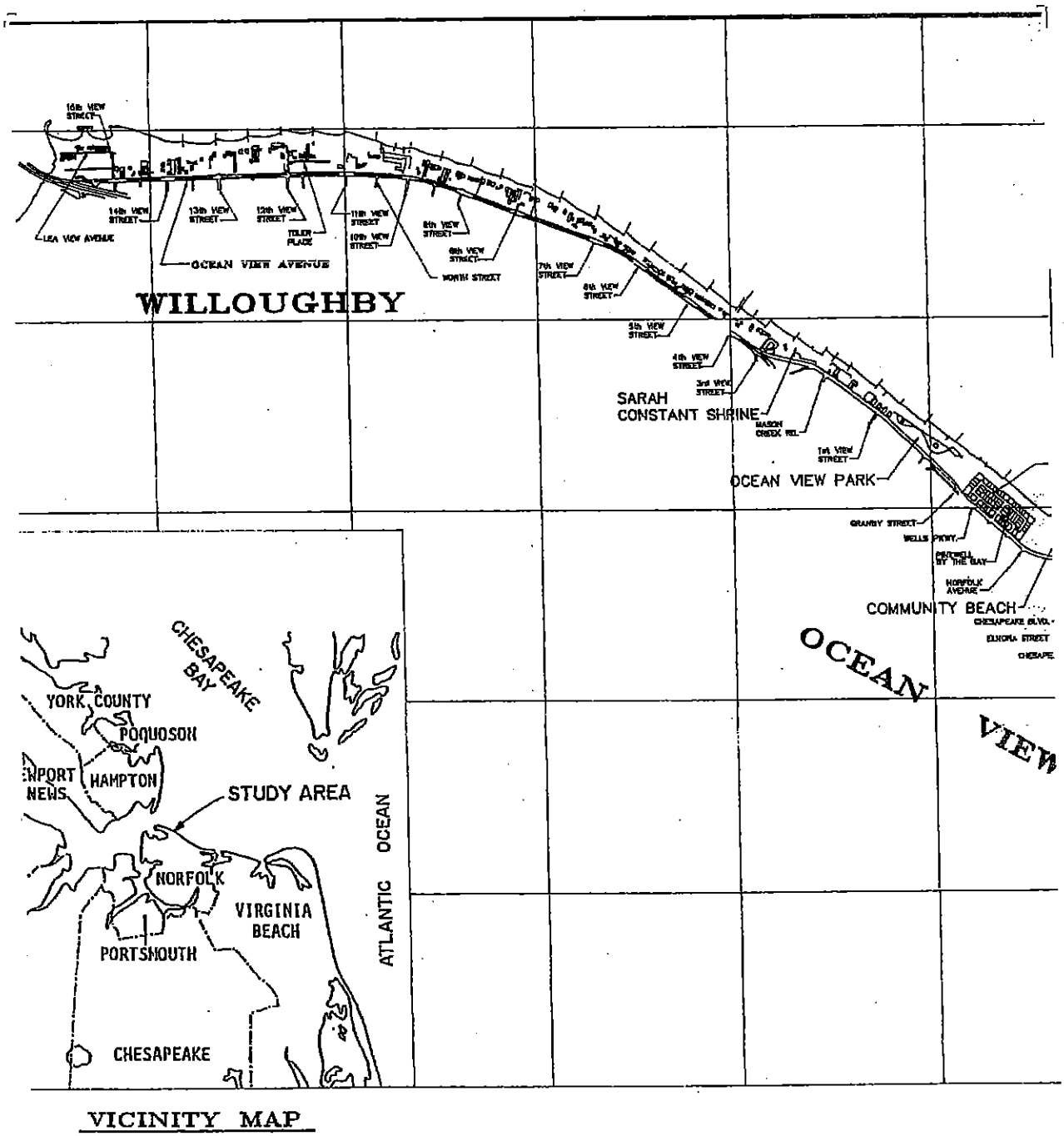

Figure 3 Schematic representation of groin field spanning Sections 1, 2, and 3 as originally constructed by the City of Norfolk in 1938

breakwaters, but the one farthest east was never constructed (White, 2003, personal communication).

Finally, seven nearshore, rubble-mound breakwaters were built in Section 6, "Little Creek Inlet". Numbers 2, 3, and 4 were finished in August 2000 and numbers 1, 5, 6, and 7 completed in November 2001. The original plan called for 10 nearshore breakwaters in this location (Andrews, Miller and Associates, 1993). At this writing, it is not known which breakwaters were not constructed.

Nearshore breakwaters are not shown on the City's AutoCADD drawings.

2.3.4 Beach Nourishment and Dune Rebuilding

Beach renourishment efforts by the City dating back to 1953 are listed and some discussed in detail in Andrews, Miller and Associates, 1993. These are summarized in Table 3 along with more recent projects (White, 2003, personal communication). At this writing, all the details (grain size, sources, etc.) are not known.

At the east end near Little Creek Inlet, 300-400 cy/ft were placed in 1953, probably from dredging the inlet (to be confirmed). Then 125-175 cy/ft were placed in later years. The December 2003 beach nourishment project is at the rate of 68 cy/ft.

By contrast, the west end projects near the Terminal Groin were at far lower volumes per unit length, i.e., only 25-50 cy/ft.

Dune repair occurred on the west end in 1988-1989 using about 35,000 cy that had accreted beyond the end of the terminal groin in place at that time.

A 1990-1991 dune stabilization/repair effort mainly focused on dune vegetation planting, sand fence construction, elevated, public accessway, cross-over structures and timber roads for vehicle access. The exact details of where the dunes were strengthened were not documented in the Beach Management Plan report (Andrews, Miller and Associates, 1993).

2.3.5 Seawalls and Bulkheads

The location, lengths, type, etc. of any seawalls and bulkheads along the Chesapeake Bay shoreline of the City of Norfolk is unknown at this writing.

TABLE 3 History of Beach Nourishments by City of Norfolk. (1953-2003)

Date [2] {End, E=East W=West}	Nourished Beach		Volume cy	Distance[5] feet	Unit Volume, cy/ft	Equilibrium[1] Yo, ft	Fill Grain Size, D_F	Source	Rmks
	From	To							
1953 (E)	18th Bay St	27th Bay St	1,260,000	3000	420	756			
1953 (E)	27th Bay St	West Jetty	500,000	1800	278	500			
1960 (E)	East End Parking Lot	West Jetty	159,000	900	177	319			
1962 (W)	Terminal Groin	9th View St	176,000	6900	25	45			
1984 (W)	Terminal Groin	5th View St	537,500	11,000	49	88	0.9 mm[4] fine to medium	Navy Piers[3]	
1984 (E)	21st Bay St	East End Parking Lot	400,000	3000	133	239		Pretty Lake	
1987 (W)	5th View St	Mason Creek	50,000	2000	25	45		Truck haul	
1989 (E)	21st Bay St	East End Parking Lot	133,000	3000	44	79	D_F=0.16 D_N=0.35	Cape Henry	
1990 (W)	Terminal Groin	-	100,000					Passed Terminal Groin	"recycle"
1995-2003	SEE APPENDIX A								

[1] Estimated closure depth, h*=10ft (Andrews, Miller and Assoc., 1993)
Estimated berm height, B=+5ft (NAVO) (White, 2003, pers.comm..) } $D_F \doteq D_N$ assumed

[2] 1953-1990/91 (Andrews, Miller and Assoc., 1993)
1992-2003 (White, 2003)

[3] Stored at Monkey Bottom

[4] Native material [0.7mm, 0.4mm, 0.2mm, Ludwick, 1987)

[5] Estimated from Figure 2 or reported in Andrews, Miller and Assoc., 1993

Section 3
Controls and Datums

3.1 Horizontal Control and Baseline

Horizontal controls and spatial positions for shorelines and the Baseline are presented in Virginia, State Plane Coordinates (South Zone). The presently used horizontal datum in the City of Norfolk is referenced to NAD 83 expressed in United States feet on all control stations and required plats.

A horizontal control Baseline was established to generally follow the curving shoreline (Figure 1) along Ocean View Avenue. Table 4 displays the initial Baseline location "bending points" on the east end near Little Creek Inlet as employed for Phase I. This Baseline was about 5220 ft long with shoreline locations found in time for the "positions" 1-29. This initial, short Baseline is essentially the extension of East Ocean View Avenue due east from 21st Bay to the jetty. Figure 4 (embedded in Table 4) demonstrates that the Baseline is a straight line when plotted in state plane coordinates. These Phase I positions, i.e., "Stations" along the Baseline were then converted to "New Station" numbers for the Final Baseline starting with 0 + 00 at the far western end of Willoughby Spit (Table 11). Shoreline positions are spaced about 200 ft apart to accommodate the nearshore breakwaters.

The Final Baseline stations numbering (1000 ft intervals) and coordinates for Phase II are presented in Table 5. because of the nearshore breakwaters constructed in the Terminal Groin area (Section 1), 8-10th View area (Section 2) and the Community Beach area (Section 4), a 200 ft spacing was used to determine shoreline positions. Table 6 presents Station numbers and coordinates for this refined, secondary level grid. The locations for all the shoreline position determinations in Phase II are seen in Figure 5. Note that Station 328 + 00 on the east end (Phase II) ends where Station 328 + 00 (formerly 52+89.) ends for Phase I which now ends at Station 380 + 89 at the Little Creek jetty.

3.2 Vertical Datum

Vertical datums for the Chesapeake Bay Bridge Tunnel, Chesapeake Bay, Virginia (Station ID 8638863) are presented in Table 7 for the 19-year tidal epoch, 1960-1978, based on 14 years of record (1976-1989). Mean lower low water (MLLW) is the NOS base elevation (0.00 feet) with mean high water (MHW) 2.72 feet above the zero elevation, vertical datum. The mean tidal range at this tidal gage station is 2.60 feet.

Standard definitions of the "shoreline" are shown in Table 8 (Corps, CETN, II-39, 1997). The mapped, mean, high-water shoreline (MHWL) or "line" is the official, NOS-determined position as interpreted by the survey party at the time of the survey. In recent years, aerial photography combined with beach profile/tidal elevations have been used to calibrate the aerial photographic data. The MHWL is related (approximately) to the MHW line rigorously determined from surveyed, beach profile data. Other defined lines taken

Table 4 Bending point and shoreline position locations along the initial, Phase I Baseline near the Little Creek Inlet

Baseline Location

Bending Point	Easting	Northing
A	12155865.00	3506707.80
B	12156569.00	3506597.80
C	12157576.00	3506431.50
D	12161003.40	3505884.96

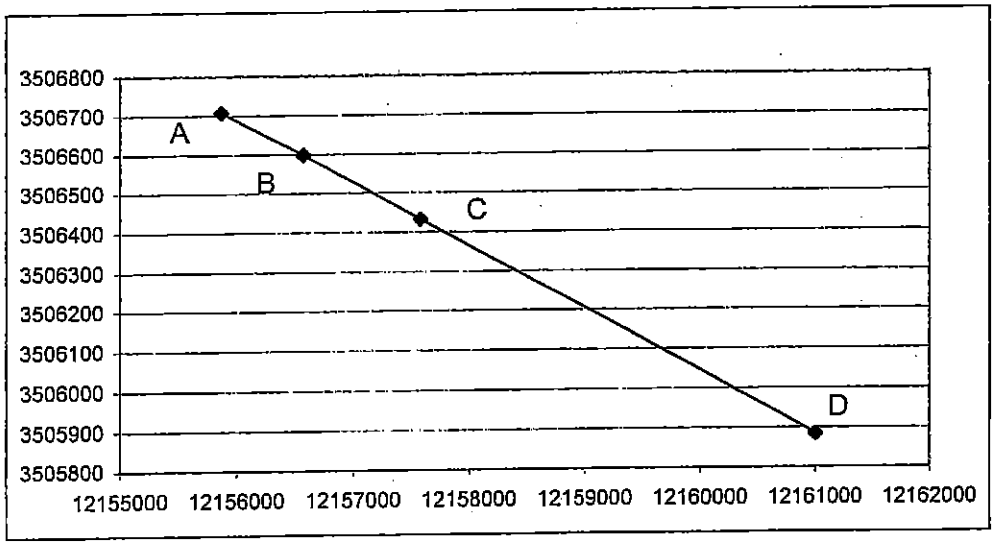

Figure 4 Initial Baseline for Phase I study, Little Creek Inlet section

Position Locations

Position	Easting	Northing
1	12155945.57	3506696.21
2	12156123.41	3506667.42
3	12156301.25	3506639.64
4	12156479.10	3506611.85
5	12156656.82	3506583.30
6	12156834.41	3506553.97
7	12157012.01	356524.64
8	12157189.60	3506495.31
9	12157367.20	3506465.98
10	12157544.79	3506436.65
11	12157722.40	3506408.15
12	12157900.04	3506379.83
13	12158077.68	3506351.50
14	12158255.32	3506323.18
15	12158432.96	3506294.85
16	12158610.60	3506266.52
17	12158788.23	3506238.20
18	12158965.87	3506209.87
19	12159143.51	3506181.54
20	12159321.15	3506153.22
21	12159500.72	3506124.58
22	12159680.31	3506095.95
23	12159857.97	3506067.62
24	12160035.46	3506039.31
25	12160213.29	3506010.96
26	12160391.11	3505982.60
27	12160568.61	3505954.30
28	12160746.27	3505925.97
29	12160923.93	3505897.64

Table 5 Station numbering and coordinates along the Phase II, Final Baseline, 1000 ft intervals, Willoughby Spit to 21st Bay Street

Station Numbering and coordinates (Ocean View, Norfolk)

Station	Easting	Northing
0+00	12126454.85	3519112.06
10+00	12127454.83	3519117.05
20+00	12128454.82	3519122.05
30+00	12129454.81	3519127.05
40+00	12130454.80	3519132.05
50+00	12131454.78	3519137.05
60+00	12132428.80	3518989.33
70+00	12133370.91	3518654.04
80+00	12134313.03	3518318.75
90+00	12135255.15	3517983.46
100+00	12136068.57	3517408.79
110+00	12136867.88	3516807.88
120+00	12137750.08	3516342.49
130+00	12138625.34	3515866.77
140+00	12139410.03	3515246.88
150+00	12140194.72	3514626.99
160+00	12140979.41	3514007.11
170+00	12141764.10	3513387.22
180+00	12142543.66	3512761.05
190+00	12143312.22	3512121.41
200+00	12144099.50	3511505.02
210+00	12144926.30	3510942.52
220+00	12145764.49	3510397.93
230+00	12146627.66	3509893.81
240+00	12147542.66	3509490.38
250+00	12148472.44	3509122.25
260+00	12149402.21	3508754.12
270+00	12150317.26	3508350.99
280+00	12151264.67	3508035.78
290+00	12152222.89	3507749.73
300+00	12153181.10	3507463.69
310+00	12154139.32	3507177.65
320+00	12155097.54	3506891.60
328+00	12155861.00	3506708.50

Table 6 Station numbering and coordinates for three areas with nearshore breakwaters, along Final Baseline, 200 ft intervals, Willoughby Spit to Atlans Street

Station Numbering and coordinates (Secondary level)

Terminal groin

Station	Easting	Northing
0+00	12126454.85	3519112.06
2+00	12126654.84	3519113.05
4+00	12126854.84	3519114.05
6+00	12127054.84	3519115.05
8+00	12127254.84	3519116.05
10+00	12127454.83	3519117.05
12+00	12127654.83	3519118.05
14+00	12127854.83	3519119.05
16+00	12128054.83	3519120.05

From 11th view st. to 6th view st.

Station	Easting	Northing
46+00	12131054.79	3519135.05
48+00	12131254.79	3519136.05
50+00	12131454.78	3519137.05
52+00	12131654.78	3519138.04
54+00	12131854.78	3519139.04
56+00	12132051.95	3519123.45
58+00	12132240.38	3519056.39
60+00	12132428.80	3518989.33
62+00	12132617.22	3518922.27
64+00	12132805.65	3518855.21
66+00	12132994.07	3518788.16
68+00	12133182.49	3518721.10
70+00	12133370.91	3518654.04
72+00	12133559.34	3518586.98
74+00	12133747.76	3518519.93
76+00	12133936.18	3518452.87
78+00	12134124.61	3518385.81
80+00	12134313.03	3518318.75
82+00	12134501.45	3518251.69
84+00	12134689.88	3518184.64
86+00	12134878.30	3518117.58
88+00	12135066.72	3518050.52
90+00	12135255.15	3517983.46
92+00	12135429.11	3517889.52
94+00	12135588.98	3517769.33

From Norfolk ave. to Atlans st.

Station	Easting	Northing
177+18	12142327.19	3512942.40
179+07	12142472.75	3512820.89
181+17	12142633.23	3512685.45
183+27	12142793.72	3512550.00
185+37	12142954.20	3512414.56
187+47	12143114.69	3512279.12
189+79	12143295.51	3512134.60

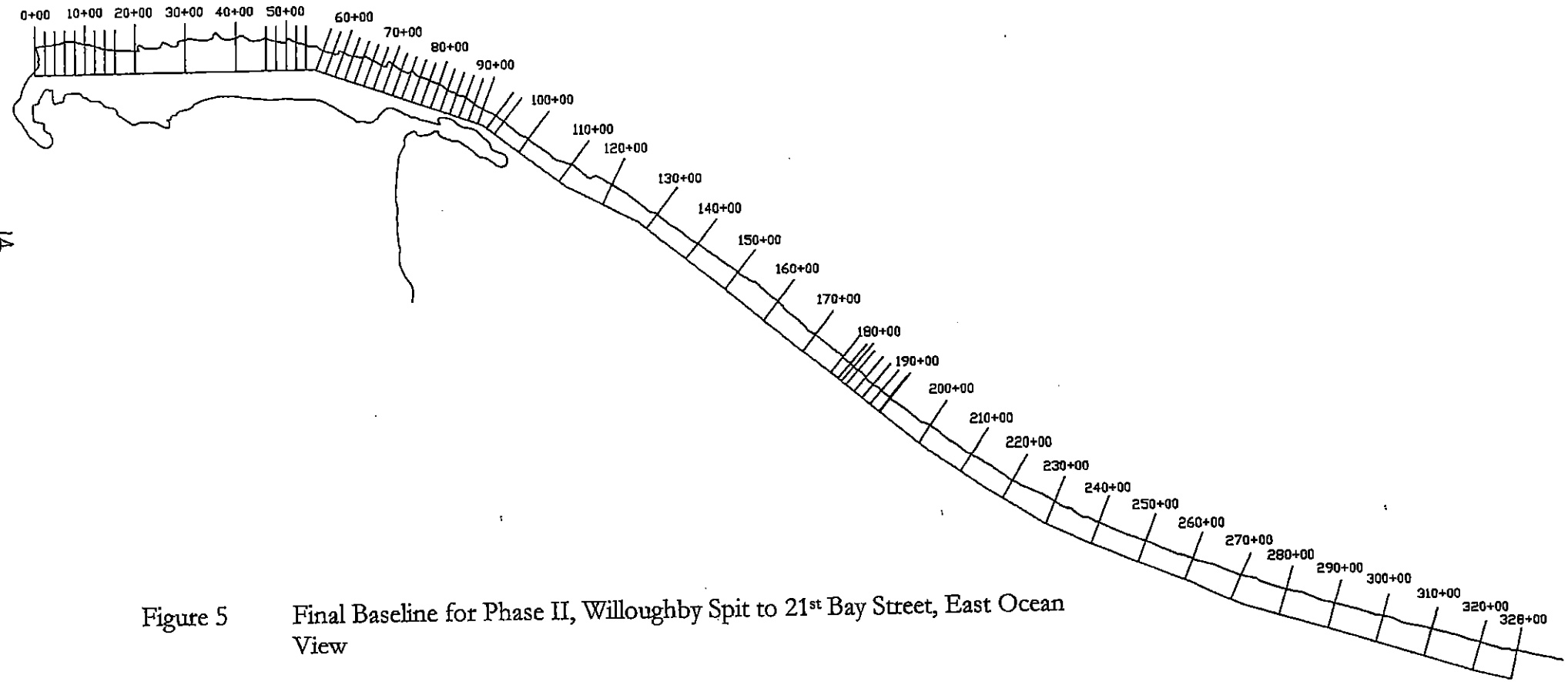

Figure 5 Final Baseline for Phase II, Willoughby Spit to 21st Bay Street, East Ocean View

Table 7 Published tidal benchmark sheet for station 8638863, CBBT from NOAA/NOS

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Service

Station ID: 8638863 **PUBLICATION DATE:** 07/24/1991
Name: CHESAPEAKE BAY BRIDGE TUNNEL, CHESAPEAKE BAY VIRGINIA
NOAA Chart: 12254 **Latitude:** 36ø 58.0' N
USGS Quad: CAPE HENRY **Longitude:** 76ø 6.8' W

T I D A L D A T U M S

Tidal datums at CHESAPEAKE BAY BRIDGE TUNNEL, CHESAPEAKE BAY based on:

LENGTH OF SERIES:	14 YEARS
TIME PERIOD:	1976-1989
TIDAL EPOCH:	1960-1978
CONTROL TIDE STATION:	8638610 HAMPTON ROADS

Elevations of tidal datums referred to Mean Lower Low Water (MLLW), in FEET:

HIGHEST OBSERVED WATER LEVEL (04/26/1978)	=	6.36
MEAN HIGHER HIGH WATER (MHHW)	=	2.95
MEAN HIGH WATER (MHW)	=	2.72
MEAN TIDE LEVEL (MTL)	=	1.42
MEAN LOW WATER (MLW)	=	0.12
MEAN LOWER LOW WATER (MLLW)	=	0.00
LOWEST OBSERVED WATER LEVEL (01/11/1978)	=	-2.54

Bench Mark Elevation Information — In FEET above:

Stamping or Designation	MLLW	MHW
NO 2 1975	27.33	24.61
NO 1 1975	25.21	22.49
NO 3 1975	27.35	24.63
13	27.30	24.58

Table 8 Standard definitions of the "shoreline" (from Corps of Engineers, CETN, II-39, 1997)

Standard Definitions of the Shoreline				
No.	**Definition**	**Measurement Procedure**	**Related to MHW?**	**Comments**
1	Mapped MHWL[1]	Interpreted from aerial photography combined with water-level measurements	Yes Approx.	Performed by NOS as part of its mapping function. Approximately related to the MHW tidal datum.
2	Surveyed	Beach profile survey tied to MHW benemarks at a tide guage	Yes Rigorous	Typically performed for property boundary delineation or as an outcome of beach profile surveying. Accurately related to a tidal datum.
3	HWL	a. Interpreted from aerial photographs b. Located from ground by interpretation combined with either land survey or GPS[2] survey	No	Definition and procedure employed by early Federal topographers and in modern topographic measurements. Not related to a tidal datum or fixed elevation, but, typically, the location of the berm crest or foot of dune or cliff.
4	Wetted bound	Aerial photography	No	Highly dependent on beach, water level, wave, and wind properties. Not related to a vertical datum.
5	Water line	Aerial photography	No	Line of the instantaneous beach-water intercept. Not related to a vertical datum.
6	Dune line Cliff line	Aerial photography; topographic survey	No	The dune line may not represent a shoreline unless interpreted as a HWL on a narrow beach without a berm. Not related to a tidal datum.

[1]MHWL denotes the mean high-water shoreline or "line".
[2]GPS denotes Global Positioning System.

from aerial photographs (toe of dune, edge of berm, etc.) can be useful for studies of shoreline movements, when consistently defined, but are not the MHW shoreline position.

Section 4
Shoreline Positions from Historic Map Data

4.1 Background and Methods

The seven historic NOS and Coast and Geodetic Survey (C&GS) shoreline survey maps (Table 2) employed varying space scales. These historic sheets were hand-digitized by the Data Translation Branch, Environmental Data and Information Service, Asheville, NC (NOAA). The repeatability error was $\pm$ 0.001 inch with maximum absolute error $\pm$ 0.003 inches. For all maps prior to NAD 27, positions were converted mathematically using special software. Early maps at 1:20,000 scale have a 30-foot accuracy in shoreline positions. The accuracy is 45 feet for a map scale of 1:30,000 (1916) and 15 feet for a map scale of 1:10,000 (1929). These are conservative, maximum error estimates. The Technical Report, CERC-83-1 "Shoreline Movements" (Everts et al., 1983) should be consulted for all technical details regarding the methods employed to develop these shoreline maps.

4.2 Digitized Shoreline Data

The original, digitized files are not available (Fromm, 1999, personal communication). Therefore, the "T-sheet" shorelines on the CD-ROM must be employed together with AutoCADD 2000 and the Baseline (Figure 5) to "measure" the shoreline distance from the Baseline for each year and at each Station along the Baseline, where data exists. Figure 2 displayed this data for Section 6, Little Creek Inlet. Figures 6, 7, and 8 show the historic, mapped shorelines for Sections 1 and 2 (Figure 6), Section 3 (Figure 7) and Sections 4 and 5 (Figure 8). The Baseline and Stations where shoreline positions are taken are also displayed on these figures.

4.3 Shoreline Locations, 1852-1963

4.3.1 Stations 0 + 00 to 328 + 00

Shoreline positions at 1000 ft intervals resulted in 34 locations from Station 0 + 00 to Station 328 + 00 (Phase II). The results are summarized in Table 9 and graphically displayed in Figure 9. Note that only years 1916 and 1963 have data for the entire length considered.

Shoreline positions at 200 ft intervals for three subregions are summarized in Tables 10(a) 0 + 00 to 16 + 00; Table 10(b) 46 + 00 to 94 + 00; and Table 10(c) 177 + 18 to 189 + 79. These subregions contain nearshore breakwaters and cover Sections 1, 2 and 4 (Figure 1).

4.3.2 Stations 328 + 67 to 379 + 09

Twenty-nine shoreline positions at approximately 180 ft intervals for Stations 328 + 67 to 379 + 09 (Phase I) are presented in Table 11. Here, only a short reach near the inlet jetty for 1876 did not contain historic map data. Note that Table 11 also includes the original,

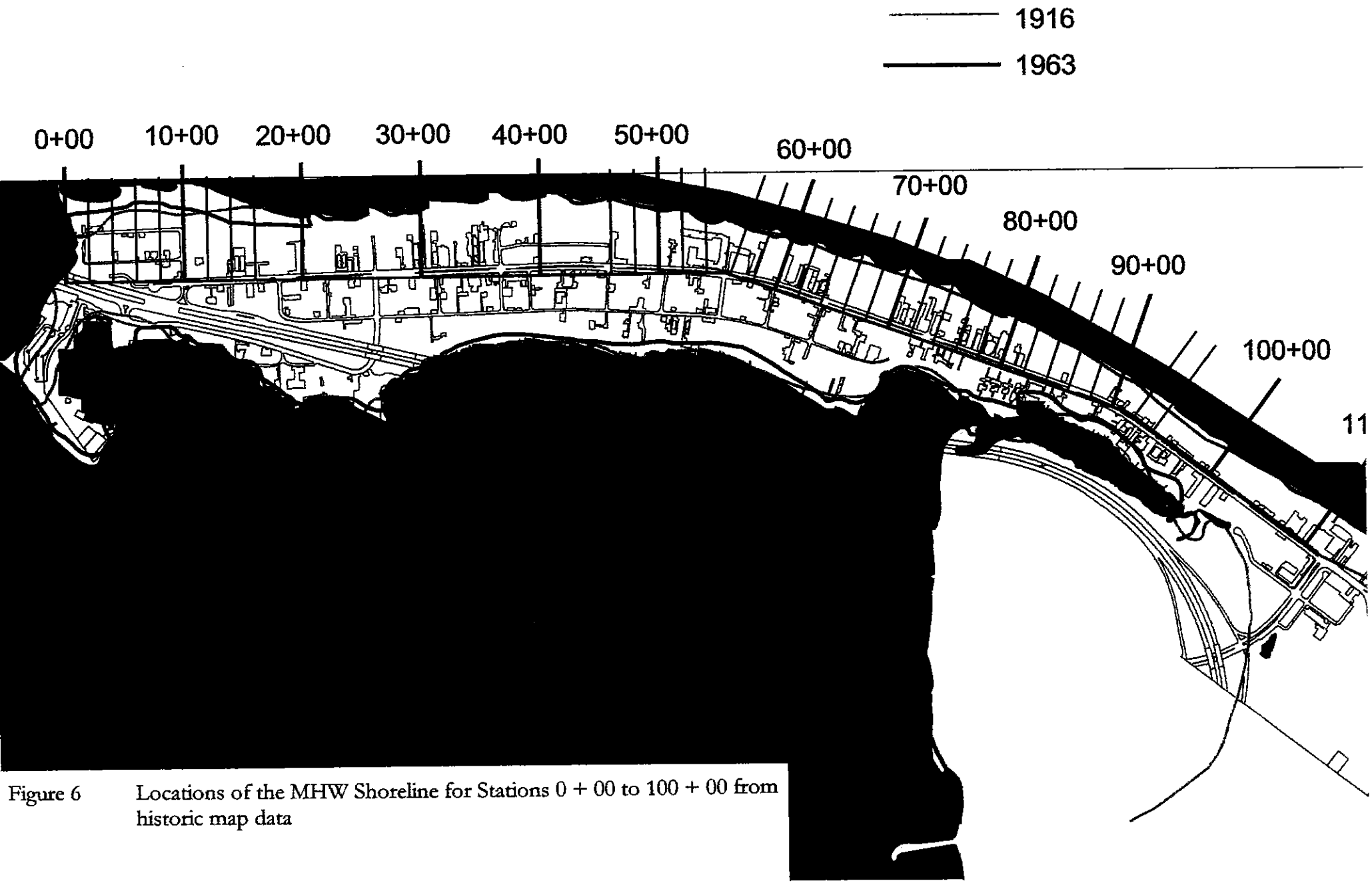

Figure 6 Locations of the MHW Shoreline for Stations 0 + 00 to 100 + 00 from historic map data

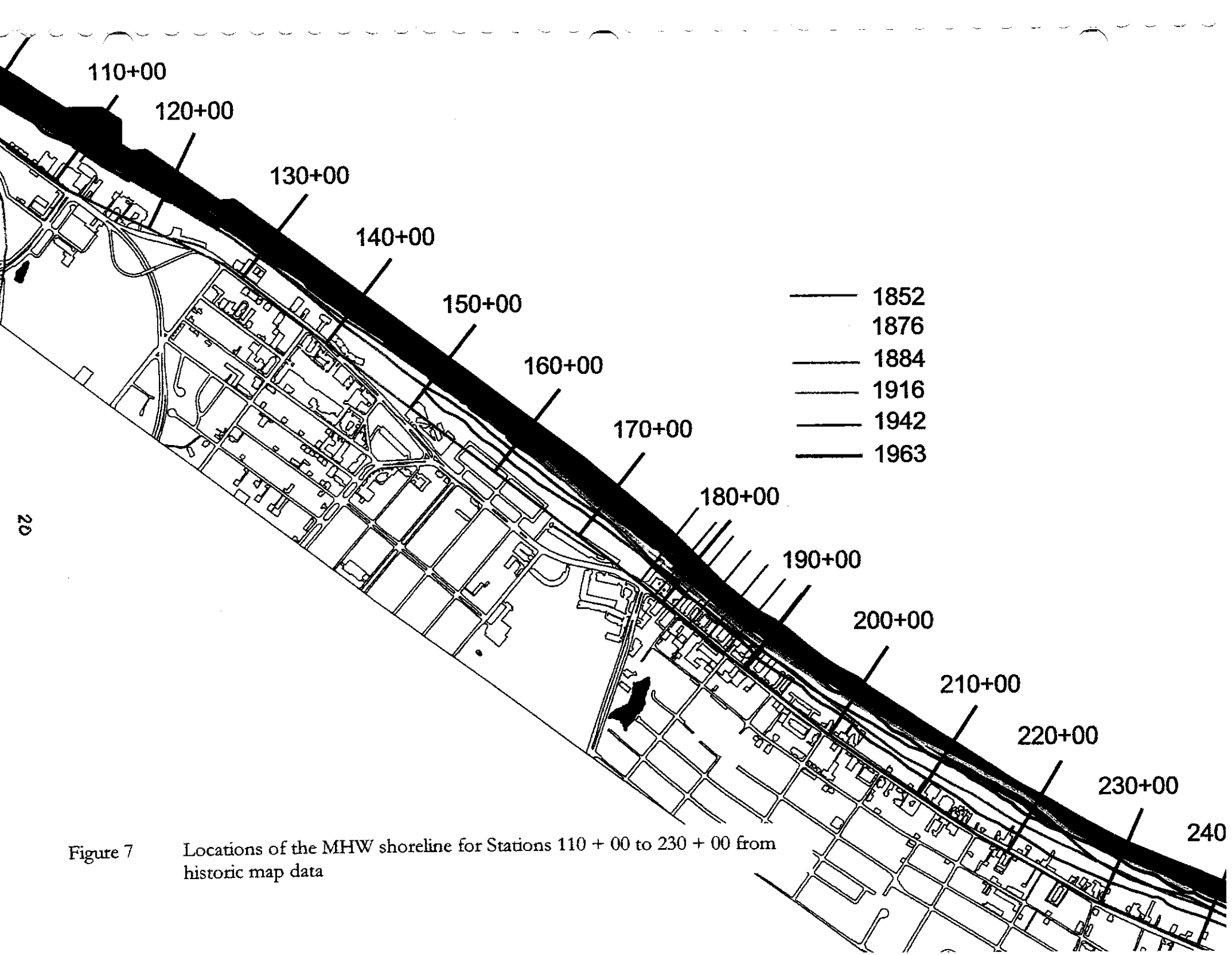

Figure 7 Locations of the MHW shoreline for Stations 110 + 00 to 230 + 00 from historic map data

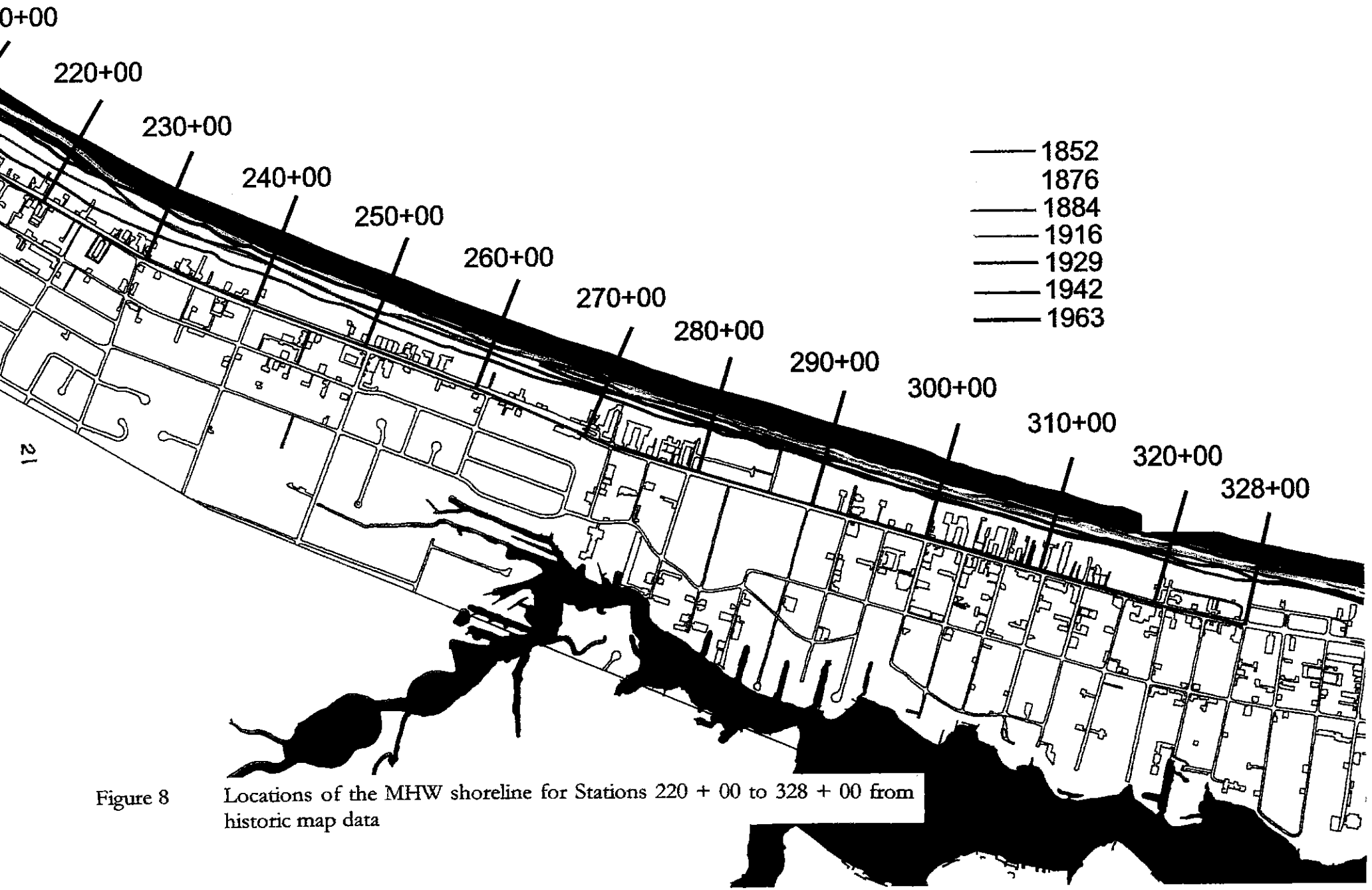

Figure 8 Locations of the MHW shoreline for Stations 220 + 00 to 328 + 00 from historic map data

Table 9 Shoreline positions at 1000 ft intervals for Stations 0 + 00 to 328 + 00 from historic map data

Shoreline Position (Oceanview, Norfolk) 1000ft

	1852	1876	1884	1916	1929	1942	1963
0+00				363.0			93.7
10+00				575.7			628.8
20+00				647.9			458.6
30+00				735.7			665.1
40+00				718.6			682.4
50+00				573.0			588.6
60+00				464.2			521.4
70+00				471.4			603.3
80+00				446.2			508.9
90+00				265.0			312.2
100+00				261.8			317.3
110+00				380.5			416.9
120+00				317.8			427.3
130+00	284.4			252.8			348.1
140+00	234.7			283.7			384.3
150+00	251.1			343.5		210.4	429.0
160+00	266.2			365.8		171.5	467.8
170+00	273.5	327.6	388.9	294.4		208.2	409.1
180+00	211.3	273.8	331.9	246.8		184.7	377.1
190+00	237.8	290.6	303.8	241.9		163.5	354.0
200+00	288.2	372.2	403.9	251.3		211.6	408.4
210+00	405.0	472.2	465.2	259.8		176.0	397.3
220+00	447.3	530.2	546.7	300.8		198.6	401.4
230+00	344.0	469.9	466.3	360.9		227.0	466.0
240+00	377.3	455.7	460.9	366.3		274.0	444.0
250+00	324.7	436.6	435.0	317.9		250.4	441.3
260+00	329.6	437.4	391.4	377.6		262.1	452.8
270+00	403.1	521.2	506.1	470.8	427.0	365.8	518.4
280+00	398.8	510.3	473.0	462.7	415.3	375.5	529.4
290+00	371.3	473.9	449.9	446.6	412.6	384.1	519.1
300+00	366.1	443.2	453.0	428.7	403.1	340.9	541.1
310+00	357.5	461.1	469.4	482.7	414.8	360.0	550.1
320+00	381.9	485.8	466.7	532.1	452.3	421.0	559.1
328+00	381.8	475.7	493.3	559.5	458.6	390.1	561.1

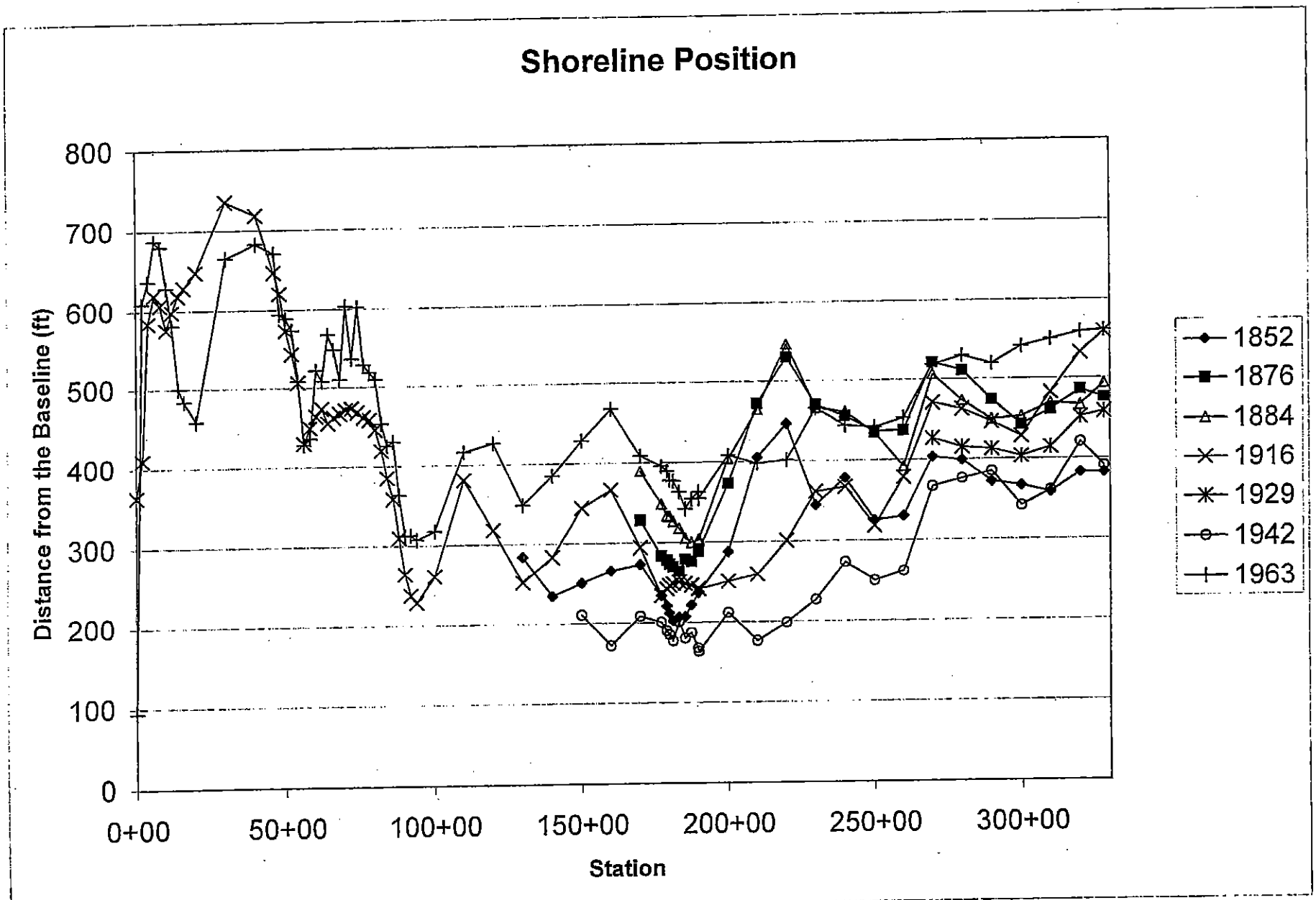

Figure 9 Shoreline positions at 1000 ft intervals for Stations 0 + 00 to 328 + 00 from historic map data

Table 10a Shoreline positions at 200 ft intervals for Stations 0 + 00 to 16 + 00 from historic map data

Shoreline Position (Oceanview, Norfolk) Terminal Groin

	1852	1876	1884	1916	1929	1942	1963
0+00				363.0			93.7
2+00				410.3			608.8
4+00				584.1			636.5
6+00				619.5			686.7
8+00				606.7			679.5
10+00				575.7			628.8
12+00				598.2			581.0
14+00				618.5			499.7
16+00				628.7			483.7

Table 10b Shoreline positions at 200 ft intervals for Stations 46 + 00 to 94 + 00 from historic map data

Shoreline Position (Oceanview, Norfolk) 11th ave to 6th ave

	1852	1876	1884	1916	1929	1942	1963
46+00				646.8			670.4
48+00				620.4			593.9
50+00				573.0			588.6
52+00				543.0			573.2
54+00				506.5			508.2
56+00				430.4			428.7
58+00				449.5			436.1
60+00				464.2			521.4
62+00				473.3			507.8
64+00				455.3			567.5
66+00				462.4			548.0
68+00				466.9			509.7
70+00				471.4			603.3
72+00				473.4			536.1
74+00				468.4			602.1
76+00				462.0			528.1
78+00				458.9			518.0
80+00				446.2			508.9
82+00				419.9			453.6
84+00				384.6			426.1
86+00				357.9			431.0
88+00				309.9			363.0
90+00				265.0			312.2
92+00				238.1			312.9
94+00				228.7			307.2

Table 10c Shoreline positions at approximately 200 ft intervals for Stations 177 + 18 to 189 + 79 from historic map data

Shoreline Position (Oceanview, Norfolk) Norfolk ave. to Atlans ave.

	1852	1876	1884	1916	1929	1942	1963
177+18	233.9	283.6	347.4	234.3		200.3	395.4
179+07	220.7	278.5	332.8	242.2		189.4	389.0
181+17	202.0	270.1	325.9	249.1		176.8	375.9
183+27	206.2	264.4	317.2	251.3		200.4	362.4
185+37	206.9	279.2	304.9	248.9		180.1	341.1
187+47	221.9	276.9	300.1	246.6		186.8	353.4
189+79	237.1	288.6	303.0	242.2		167.5	362.0

Table 11 Shoreline positions at approximately 180 ft intervals for Stations 328 + 67 to 379 + 09 from historic map data

Shoreline Positions at the West Side of Little Creek Inlet (ft)

Position	Station	New Station	1852	1876	1884	1916	1929	1942	1963
1	52+22.26	328+67	385.68	471.65	488.29	556.25	449.83	379.16	559.80
2	50+42.26	330+47	403.54	470.33	502.18	541.34	433.95	387.21	549.54
3	48+62.27	332+27	407.61	462.44	519.09	530.32	415.35	387.51	536.13
4	46+82.27	334+07	385.45	460.74	520.31	521.78	396.53	377.00	526.86
5	45+02.28	335+87	381.08	457.30	486.05	526.02	386.00	355.16	526.08
6	43+22.28	337+67	353.03	431.34	449.83	505.16	365.85	330.21	511.23
7	41+42.28	339+47	327.76	400.84	434.09	509.14	357.60	312.59	467.51
8	39+62.28	341+27	322.74	398.01	413.93	516.05	358.75	301.29	460.01
9	37+82.28	343+07	328.29	396.49	402.46	515.45	381.72	302.71	446.48
10	36+02.27	344+87	342.51	393.80	401.79	516.39	342.10	289.22	427.37
11	34+22.39	346+67	337.90	404.27	404.47	500.51	334.98	259.65	417.22
12	32+42.51	348+47	324.18	413.93	406.62	494.05	341.48	237.96	401.51
13	30+62.63	350+26	318.33	435.11	407.19	487.37	354.59	226.33	368.41
14	28+82.75	352+06	307.37	438.61	421.22	483.86	355.32	243.73	363.73
15	27+02.87	353+86	297.53	437.97	446.32	480.91	348.13	221.60	345.26
16	25+22.99	355+66	298.80	437.28	448.16	476.47	338.64	196.31	348.31
17	23+43.11	357+46	310.35	441.91	450.10	474.40	330.53	187.22	331.72
18	21+63.23	359+26	327.46	445.79	474.51	481.31	327.79	125.22	312.08
19	19+83.35	361+06	380.58	457.68	498.88	477.48	335.59	106.01	311.32
20	18+03.47	362+86	409.25	468.06	506.62	473.34	321.85	86.87	321.62
21	16+21.63	364+67	420.90	480.39	537.25	467.18	342.60	84.87	307.74
22	14+39.78	366+49	451.33	490.52	546.13	468.59	321.32	104.33	293.41
23	12+59.88	368+29	445.87	483.78	469.59	473.38	298.82	113.26	297.77
24	10+80.15	370+09	482.62	529.64	586.39	479.09	298.16	98.00	298.30
25	9+00.08	371+89	492.41	539.42	586.39	494.36	291.48	101.15	296.17
26	7+20.01	373+69	492.13		592.43	497.26	288.37	124.40	288.85
27	5+40.27	375+49	487.07		597.71	499.19	341.29	129.16	294.17
28	3+60.37	377+29	477.41		597.84	489.49	421.15	156.52	334.33
29	1+80.47	379+09	476.98		592.50	487.97	454.96	210.17	418.69

Phase I position and Station numbering system used in our initial report (August 9, 2003, data only). Figure 10 presents the trends.

Finally, Figure 11 displays the historic map data over the 112 years (1852-1963) for the seven years of record and at all 29 shoreline positions. Shoreline positions varied by about 200 ft from the Baseline over this approximately one-mile distance west of the Little Creek Inlet prior to jetty construction (1852, 1876, 1884, 1916). Immediately after jetty construction (1929) the variation was the lowest ever and less than 100 ft. Since then, the shoreline position variability has increased to 250-300 ft in the landward-seaward directions.

4.4 Historic Shoreline Change Rates

4.4.1 Prior to Jetty Construction (1852-1916)

The construction of the jetties at Little Creek Inlet in 1926-28 stabilized the inlet location (see Figure 2) and created major changes (erosion) of the shoreline immediately west of the inlet (Table 11). Table 12 summarizes the shoreline position change rates (ft/yr) for a number of intervals between surveys. The 65 yr period before jetty construction (1852-1916) displays almost all position change rates (except Station 370 + 09) with an average of + 1.75 ft/yr accretion for Section 6 between Stations 328 + 67 and 379 + 09. The western jetty is at Station 380 + 90. Figure 12 displays the before jetty construction trends in space (circles) along with the other change rates in Table 12.

From the tip of Willoughby Spit (Station 0 + 00) to Station 328 + 00, the results are less clear because the map data coverage of the shoreline is incomplete. Table 13 (top) displays the before jetty change rates from Station 150 + 00 to 320 + 00 at 1000 ft intervals with more detailed coverage in Table 13 (bottom) for Station 177 + 18 to 189 + 79. The 65 yr average was again positive (accretion) for both the large area (+0.42 ft/yr, 3.2 miles) and the short, detailed subregion (+0.42 ft/yr, 0.24 miles). Note that no change rates could be calculated between Station 0 + 00 and Station 120 + 00 because no survey in 1852 existed over this reach. Spatial variability in the 1852-1916 change rate from Station 150 + 00 to 320 + 00 is displayed in Figure 13 along with some other rates.

4.4.2 After Jetty Construction (1929 - 1963)

The period 1916-1929 (14 yrs) spans the time when the jetties were built (1926-1928) and gives the greatest negative (erosion) shoreline change rates. Near the Little Creek Inlet jetty, Table 12 shows the erosion rate varied from about –8 ft/yr to –16 ft/yr (except right next to the jetty) with an average erosion rate of –10.9 ft/yr over this one mile stretch of shoreline. For the next 14 years (1929-1942) the jetties continued to starve the western beach at an average erosion rate of –10.3 ft/yr.

Further west another 6800 ft (1.3 mi) between Stations 260 + 00 and 328 + 00, the 1916-1929 erosion rate varied from –2 ft/yr to –8 ft/yr with average of –4.4 ft/yr. And again,

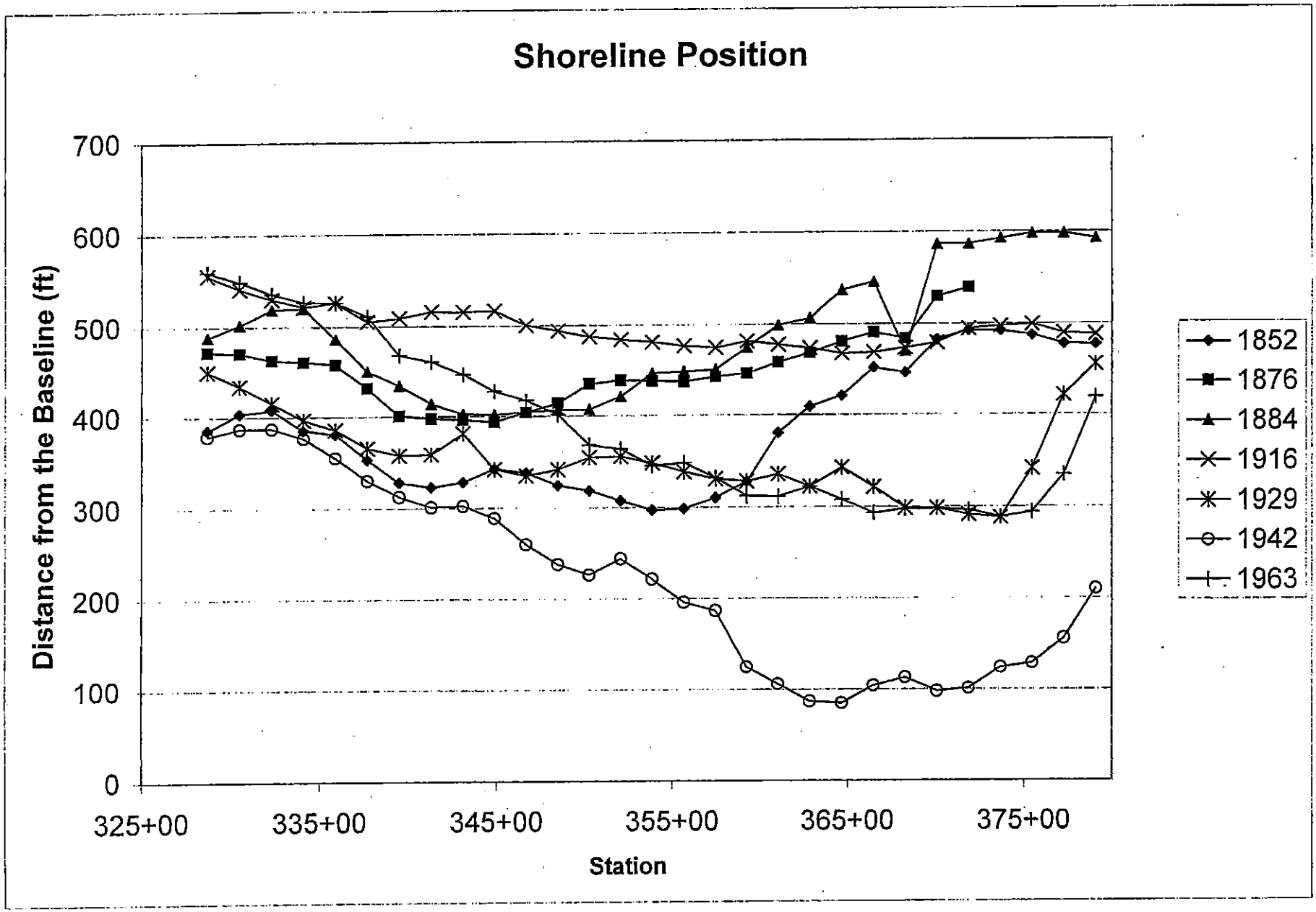

Figure 10 Shoreline positions at approximately 180 ft intervals for Stations 328 + 67 to 379 + 09 from historic map data

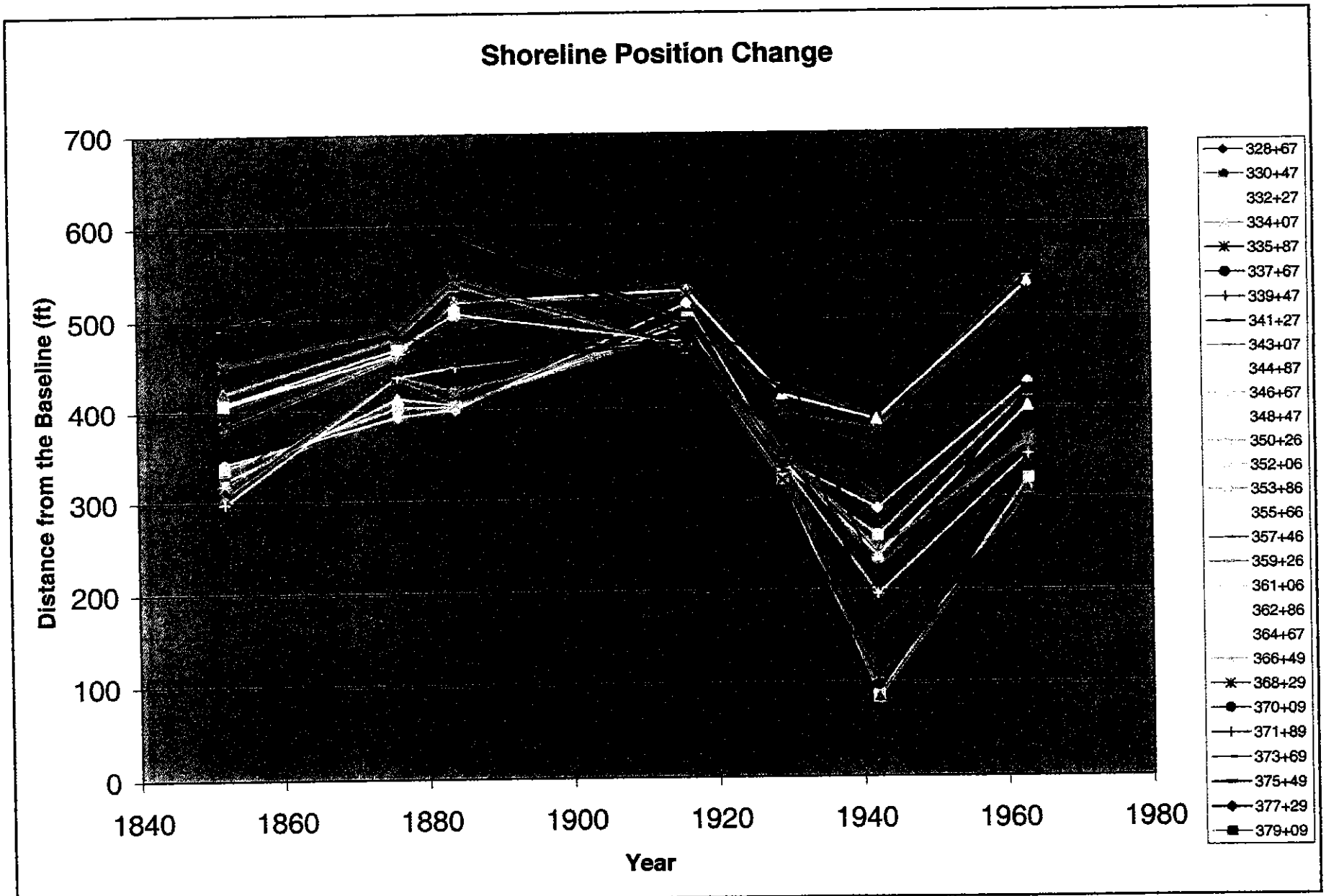

Figure 11 Graphical representation of shoreline position variability in time along the one-mile shoreline west of the Little Creek Inlet, 1852-1963

Table 12 Shoreline position change rates (ft/yr) for both before and after jetty construction (1926-28) from historic map data immediately west of Little Creek Inlet

Shoreline Position Change Rate at the West Side of Little Creek Inlet (ft/yr)

Position	Station	New Station	1852-1876	1876-1884	1884-1916	1916-1929	1929-1942	1942-1963	1852-1916	1916-1963	1929-1963
1	52+22.26	328+67	3.58	2.08	2.12	-8.19	-5.44	8.60	2.67	0.08	-3.23
2	50+42.26	330+47	2.78	3.98	1.22	-8.26	-3.60	7.73	2.15	0.17	-3.40
3	48+62.27	332+27	2.28	7.08	0.35	-8.84	-2.14	7.08	1.92	0.12	-3.55
4	46+82.27	334+07	3.14	7.45	0.05	-9.63	-1.50	7.14	2.13	0.11	-3.83
5	45+02.28	335+87	3.18	3.59	1.25	-10.77	-2.37	8.14	2.26	0.00	-4.12
6	43+22.28	337+67	3.26	2.31	1.73	-10.72	-2.74	8.62	2.38	0.13	-4.28
7	41+42.28	339+47	3.05	4.16	2.35	-11.66	-3.46	7.38	2.83	-0.89	-3.23
8	39+62.28	341+27	3.14	1.99	3.19	-12.10	-4.42	7.56	3.02	-1.19	-2.98
9	37+82.28	343+07	2.84	0.75	3.53	-10.29	-6.08	6.85	2.92	-1.47	-1.90
10	36+02.27	344+87	2.14	1.00	3.58	-13.41	-4.07	6.58	2.72	-1.89	-2.51
11	34+22.39	346+67	2.77	0.03	3.00	-12.73	-5.79	7.50	2.54	-1.77	-2.42
12	32+42.51	348+47	3.74	-0.91	2.73	-11.74	-7.96	7.79	2.65	-1.97	-1.77
13	30+62.63	350+26	4.87	-3.49	2.51	-10.21	-9.87	6.77	2.64	-2.53	-0.41
14	28+82.75	352+06	5.47	-2.17	1.96	-9.89	-8.58	5.71	2.76	-2.56	-0.25
15	27+02.87	353+86	5.85	1.04	1.08	-10.21	-9.73	5.89	2.87	-2.89	0.08
16	25+22.99	355+66	5.77	1.36	0.88	-10.60	-10.95	7.24	2.78	-2.73	-0.28
17	23+43.11	357+46	5.48	1.02	0.76	-11.07	-11.02	6.88	2.56	-3.04	-0.04
18	21+63.23	359+26	4.93	3.59	0.21	-11.81	-15.58	8.90	2.40	-3.60	0.46
19	19+83.35	361+06	3.21	5.15	-0.67	-10.91	-17.66	9.78	1.51	-3.54	0.71
20	18+03.47	362+86	2.45	4.82	-1.04	-11.65	-18.08	11.18	1.00	-3.23	0.01
21	16+21.63	364+67	2.48	7.11	-2.19	-9.58	-19.83	10.61	0.72	-3.39	1.03
22	14+39.78	366+49	1.63	6.95	-2.42	-11.33	-16.69	9.00	0.27	-3.73	0.82
23	12+59.88	368+29	1.58	-1.77	0.12	-13.43	-14.27	8.79	0.43	-3.74	0.03
24	10+80.15	370+09	1.96	7.09	-3.35	-13.92	-15.40	9.54	-0.06	-3.85	0.00
25	9+00.08	371+89	1.96	5.87	-2.88	-15.61	-14.64	9.29	0.03	-4.22	-0.14
26	7+20.01	373+69			-2.97	-16.07	-12.61	7.83	0.08	-4.43	-0.01
27	5+40.27	375+49			-3.08	-12.15	-16.32	7.86	0.19	-4.36	1.39
28	3+60.37	377+29			-3.39	-5.26	-20.36	8.47	0.19	-3.30	2.55
29	1+80.47	379+09			-3.27	-2.54	-18.83	9.93	0.17	-1.47	1.07
Average			3.34	2.80	0.25	-10.85	-10.34	8.09	1.75	-2.25	-1.04

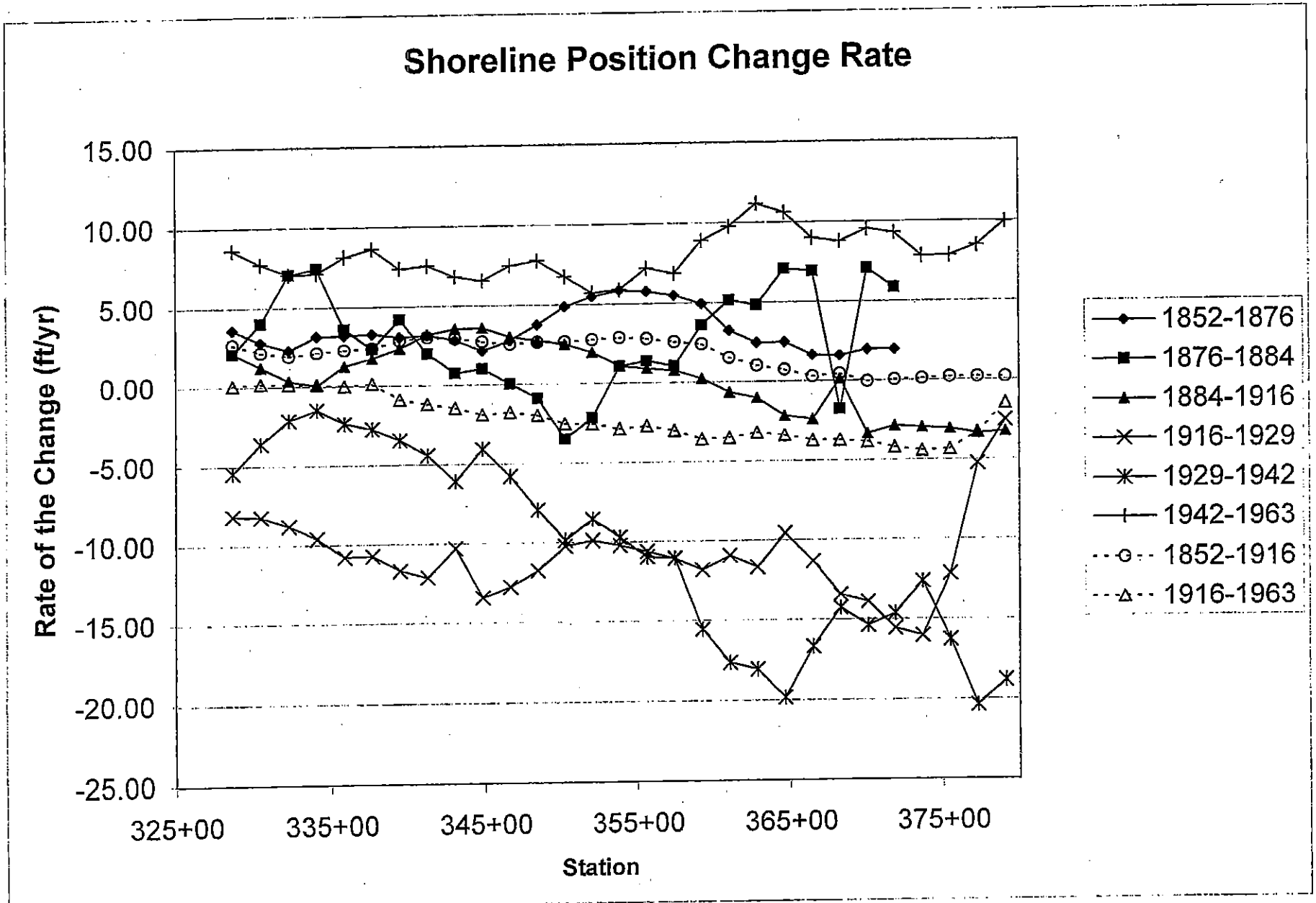

Figure 12 Shoreline position change rates (ft/yr) for both before and after jetty construction (1926-28) from historic map data immediately west of Little Creek Inlet

Table 13 Shoreline position change rates (ft/yr) for both before and after jetty construction (1926-28) from historic map data at Stations where data exists

Shoreline position change rate(ft/yr), 1000ft

	Before the jetty was built				After
	1852-1876	1876-1884	1884-1916	1852-1916	1942-1963
150+00				1.44	10.41
160+00				1.56	14.11
170+00	2.25	7.66	-2.96	0.33	9.57
180+00	2.60	7.26	-2.66	0.55	9.16
190+00	2.20	1.65	-1.93	0.06	9.07
200+00	3.50	3.96	-4.77	-0.58	9.37
210+00	2.80	-0.87	-6.42	-2.27	10.54
220+00	3.46	2.06	-7.68	-2.29	9.66
230+00	5.24	-0.45	-3.30	0.26	11.38
240+00	3.27	0.65	-2.96	-0.17	8.09
250+00	4.66	-0.20	-3.66	-0.11	9.09
260+00	4.49	-5.75	-0.43	0.75	9.08
270+00	4.92	-1.88	-1.10	1.06	7.27
280+00	4.65	-4.67	-0.32	1.00	7.33
290+00	4.27	-3.00	-0.10	1.18	6.43
300+00	3.21	1.23	-0.76	0.98	9.53
310+00	4.32	1.04	0.41	1.96	9.05
320+00	4.33	-2.38	2.04	2.35	6.58

Shoreline position change rate (ft/yr), Norfolk ave. to Atlans ave.

	Before the jetty was built				After
	1852-1876	1876-1884	1884-1916	1852-1916	1942-1963
177+18	2.07	7.97	-3.54	0.01	9.29
179+07	2.41	6.79	-2.83	0.34	9.51
181+17	2.84	6.97	-2.40	0.74	9.48
183+27	2.42	6.61	-2.06	0.70	7.72
185+37	3.01	3.22	-1.75	0.66	7.67
187+47	2.29	2.90	-1.67	0.39	7.94
189+79	2.15	1.80	-1.90	0.08	9.26

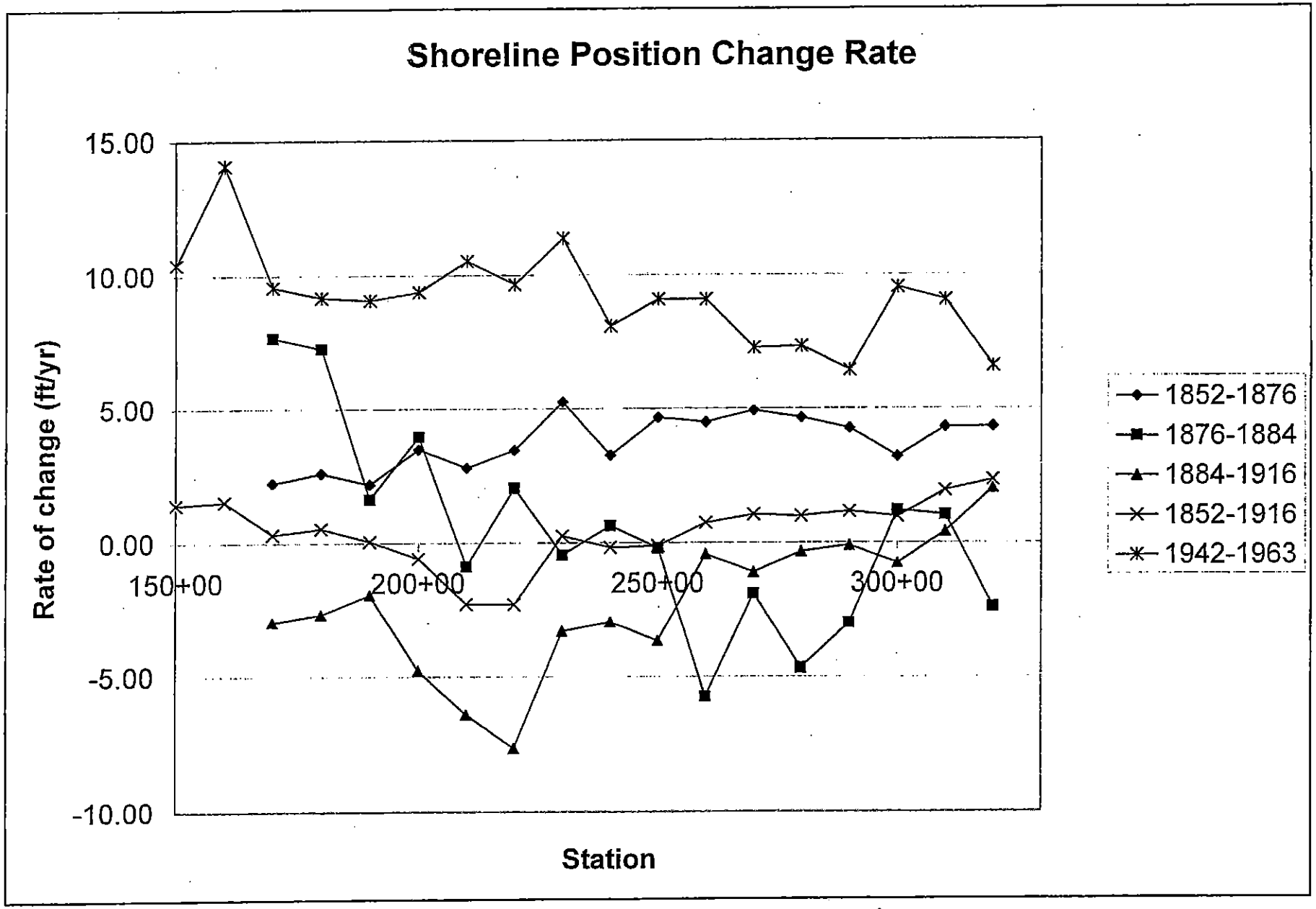

Figure 13 Shoreline position change rates (ft/yr) for before and after jetty construction (1926-28) from historic map data for Station 150 + 00 to 320 + 00

over the next 14 years (1929-1942) this location experienced an average erosion rate of minus 3.8 ft/yr.

From Station 0 + 00 to Station 260 + 00, no data exists for 1929; consequently the initial impact of jetty construction on this western 4.9 miles of shoreline to Willoughby Spit cannot be determined. However, as discussed above in Section 2.3.2, the private property owners and then the City of Norfolk constructed the groin fields in an attempt to overcome the erosional impacts of the jetties. In addition, beach nourishments were conducted in 1953 and 1960 near the jetties and in 1962 of the terminal groin (Table 3). These coastal engineering works (groins, beach replenishments) also alter the natural, historic shoreline change rates up until 1963 which was the last map data available.

Between 1942 and 1963 (22 years), the shoreline change rate was significantly positive, averaging +8.1 ft/yr for the one-mile area west of Little Creek Inlet. Further west for 3.2 miles, the average accretion rate was +9.2 ft/yr. These values are undoubtedly influenced by the 1,760,000 cy placed in 1953 and the 159,000 cy placed in 1960 as beach nourishment.

For completeness, we have calculated the shoreline change rates for the period 1916-1963 (48 years) that includes the impacts of the jetties, groins and beach nourishments. Table 14 displays these results between Stations 0 + 00 and 328 + 00, including subreaches at closer intervals, and Table 12 presented the results for the near inlet, Section 6 reach from Station 328 + 67 to 379 + 09. In general, over this 48-year period, the shoreline has remained stable to accretionary over most of the length, except near the jetties (Station 340 to 380) and near the terminal groin (Station 0 + 00 to 40 + 00). Figures 12 and 14 display these trends, respectively.

Table 14 Shoreline position change rates (ft/yr) for the 48 years (1916-1963) after coastal works, from Station 0 + 00 to 328 + 00, and subreaches.

Shoreline position change rate (ft/yr)

1000ft

	1916-1963
0+00	-5.73
10+00	1.13
20+00	-4.03
30+00	-1.50
40+00	-0.77
50+00	0.33
60+00	1.22
70+00	2.81
80+00	1.33
90+00	1.00
100+00	1.18
110+00	0.78
120+00	2.33
130+00	2.03
140+00	2.14
150+00	1.82
160+00	2.17
170+00	2.44
180+00	2.77
190+00	2.39
200+00	3.34
210+00	2.93
220+00	2.14
230+00	2.24
240+00	1.65
250+00	2.63
260+00	1.60
270+00	1.01
280+00	1.42
290+00	1.54
300+00	2.39
310+00	1.43
320+00	0.58
328+00	0.03

Terminal groin

	1916-1963
0+00	-5.73
2+00	4.22
4+00	1.11
6+00	1.43
8+00	1.55
10+00	1.13
12+00	-0.37
14+00	-2.53
16+00	-3.08

11th st. to 6th st.

	1916-1963
46+00	0.50
48+00	-0.56
50+00	0.33
52+00	0.64
54+00	0.04
56+00	-0.03
58+00	-0.29
60+00	1.22
62+00	0.73
64+00	2.39
66+00	1.82
68+00	0.91
70+00	2.81
72+00	1.33
74+00	2.84
76+00	1.41
78+00	1.26
80+00	1.33
82+00	0.72
84+00	0.88
86+00	1.56
88+00	1.13
90+00	1.00
92+00	1.59
94+00	1.67

Chesapeake Blvd. To Atlans ave.

	1916-1963
177+18	3.43
179+07	3.12
181+17	2.70
183+27	2.36
185+37	1.96
187+47	2.27
189+79	2.55

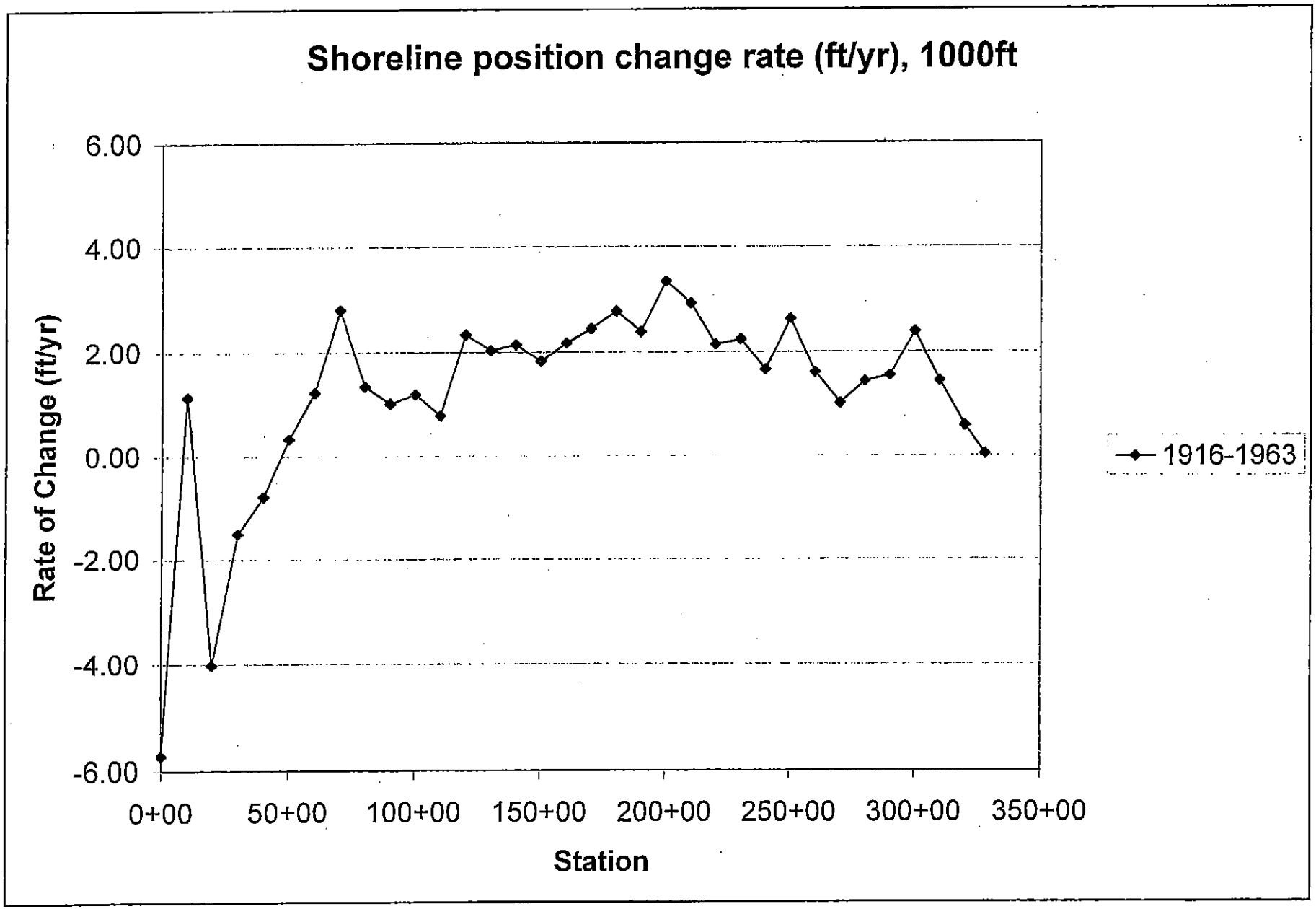

Figure 14 Shoreline position change rates (ft/yr) for the 48 years (1916-1963) after coastal works, from Station 0 + 00 to 328 + 00

Section 5
Aerial Photographic Data

5.1 Background and Methods

Aerial photographs from the archives of the Virginia Institute of Marine Science (VIMS) for portions of the Chesapeake Bay shoreline from Little Creek Inlet to Willoughby Spit were obtained in two formats. For the years 1937, 1956, 1970, 1976, and 1980, the photographs were made available on a CD-ROM in .tif format. In this format, the photos could be directly imported into AutoCADD, and the photo scale determined by known horizontal distances of recognizable features. The Baseline and Station locations were then added so that shoreline positions could be determined.

For the years 1995, 1999, and 2002, the photographs were only available in hard copy format. In this case, the Baseline was located directly on the hard copy and recognizable features again utilized together with their known distance from AutoCADD to determine the photo scale. Shoreline positions were then scaled and adjusted to true scale.

In general, this photographic data of shoreline positions was at a scale of approximately 1 inch equals 200 ft. Figure 15 is an example for the year 2002 for Station 172 + 93 to 188 +27.

5.2 Shoreline Positions and Change Rates (1937-1980)

5.2.1 Shoreline Positions

Table 15 summarizes shoreline positions from Station 0 + 00 to Station 328 + 00 at 1000 ft intervals. Note the sporadic coverage, especially west of Station 80 + 00. The spatial trends are revealed in Figure 16 and are far more variable than the temporal variation over this 44-year period. Table 16(a) displays the shoreline locations in more detail for Station 0 + 00 to 16 + 00 (1976); Table 16(b) is for Station 46 + 00 to 94 + 00; and Table 16(c) for Station 177 + 18 to 189 + 79.

For the one-mile shoreline near Little Creek Inlet, Table 17 summarizes the available results. Again, the aerial coverage is incomplete. Figure 17 displays the trends which reveal a relatively constant recession of the shoreline over the 44-yr period of record.

5.2.2 Shoreline Change Rates

As demonstrated in Table 18 and Figure 18, the change rates are highly variable, positive and negative for the shoreline between the tip of Willoughby Spit (0 + 00) and 21st Bay Street (328 + 00). However, for the 44-year period (1937- 1980), the shoreline change rate was positive from Station 80 + 00 to 260 + 00, with average value of +0.92ft/yr. Then from Station 270 + 00 to 328 + 00, it was negative, with average equal –0.84ft/yr. Note that the 1937-1956 period of 20 years was almost all negative from Station 190 + 00 to 328

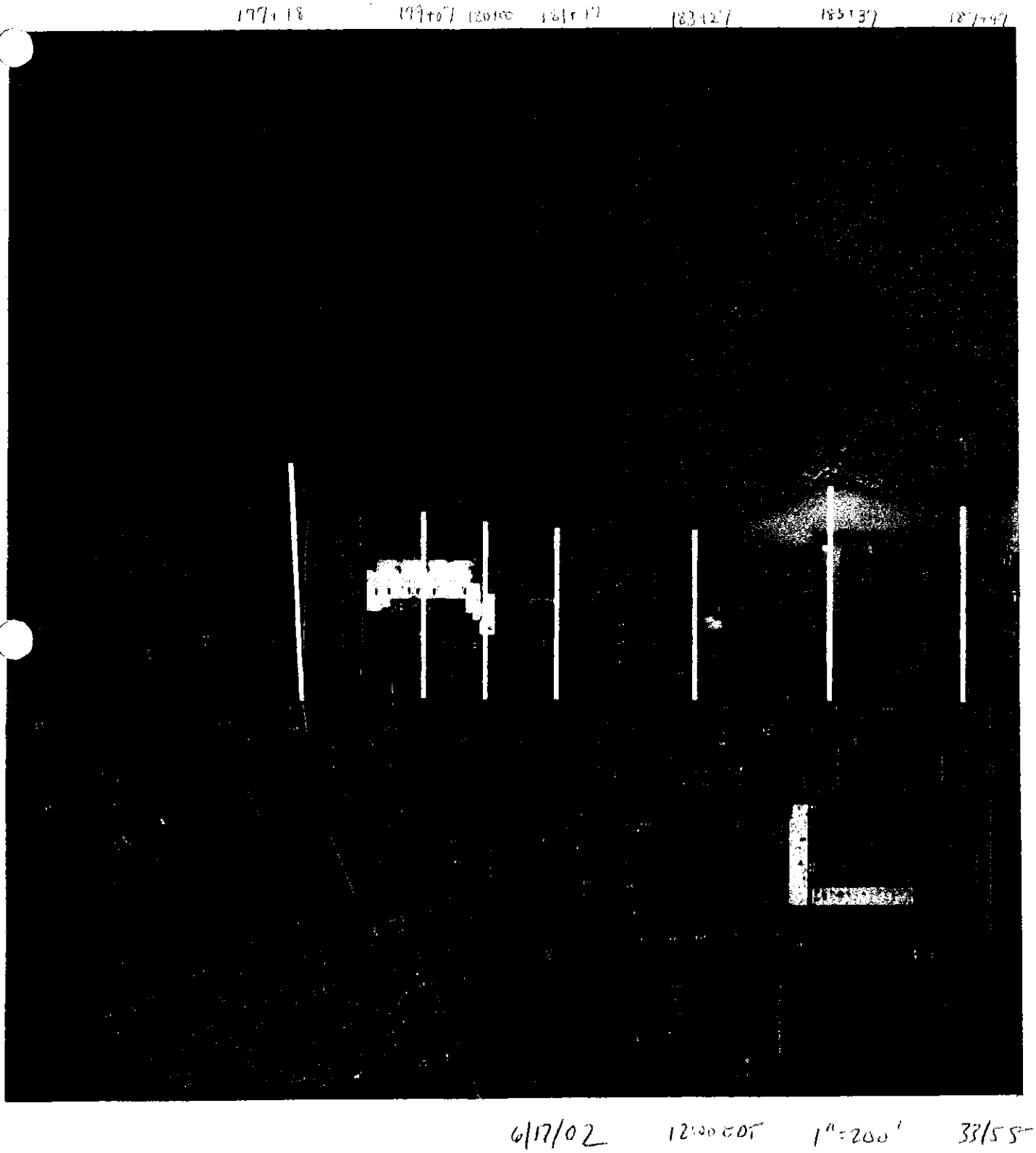

Figure 15 An example of hard copy shoreline photograph for 2002, Station 172 + 93 to 188 + 27

Table 15 Shoreline positions at 1000 ft intervals for Stations 0 + 00 to 328 + 00 from aerial photographic data, 1937, 1956, 1970, 1976 and 1980.

Shoreline position (Aerial photograph, 1937-1980)

	1937	1956	1970	1976	1980
0+00				576.30	
10+00				550.10	
20+00				430.89	
30+00		610.09		538.30	
40+00		539.90		618.65	
50+00		524.03		506.04	
60+00		455.19		449.83	
70+00		521.54		488.37	
80+00	381.65	443.31	434.45	438.04	457.99
90+00	255.75	235.37	280.03	290.08	284.18
100+00	239.24	258.43	268.09	267.97	278.67
110+00	313.64	285.11	336.39	340.52	335.08
120+00	322.09		307.72	298.57	309.79
130+00	275.55		286.33	311.16	317.56
140+00	281.69		313.62	319.84	328.36
150+00	301.91		362.88	367.33	369.55
160+00	294.98		375.95	392.33	381.25
170+00	290.41		364.58	381.56	367.96
180+00	259.96		303.57	291.67	295.73
190+00	307.92	304.20		320.37	
200+00	347.28	353.77		357.95	
210+00	337.53	323.64		383.76	396.72
220+00	405.01	342.89	370.13	379.54	432.00
230+00	418.46	365.72	404.83	423.32	452.78
240+00	430.59	379.48	402.23	425.12	444.17
250+00	402.43	346.82	370.00	383.39	413.51
260+00	420.48	374.43	393.46	392.39	439.29
270+00	527.92	484.79	468.69	480.40	499.31
280+00	527.92	493.90	485.52	511.68	515.13
290+00	533.31	465.91	465.10	490.91	481.77
300+00	525.55	454.81	463.49	481.01	478.89
310+00	529.77	450.94	476.28	492.93	491.76
320+00	535.40	507.86	509.10	499.12	508.41
328+00	547.95	488.14	489.10	490.18	500.27

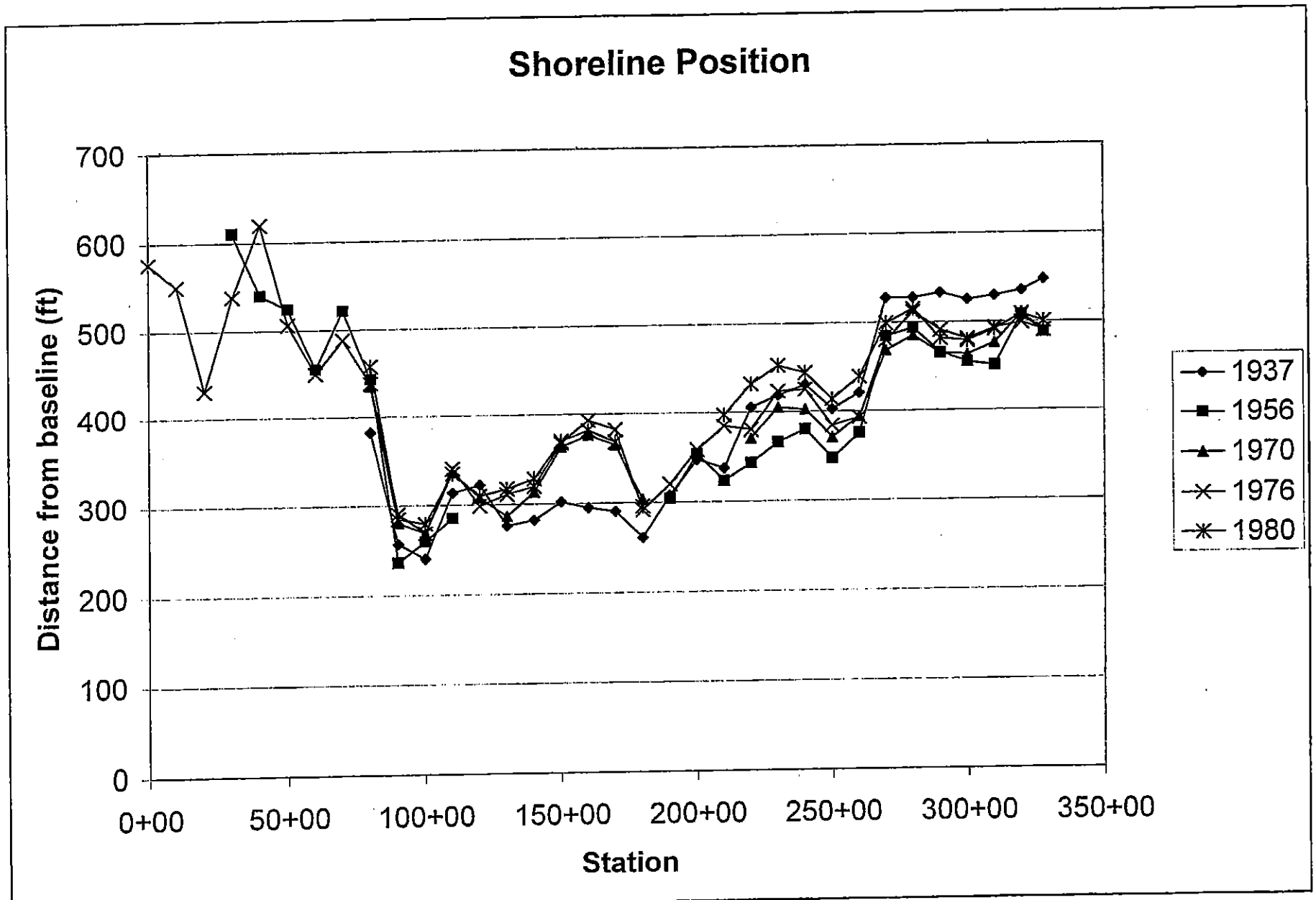

Figure 16 Shoreline positions at 1000 ft intervals for Stations 0 + 00 to 328 + 00 from aerial photographic data, 1937, 1956, 1970, 1976 and 1980

Table 16 Shoreline positions at 200 ft intervals for (a) Station 0 + 00 to 16 + 00 (1976), (b) Station 46 + 00 to 94 + 00, and (c) Station 177 + 18 to 189 + 79

(a) terminal groin

	1937	1956	1970	1976	1980
0+00				576.3	
2+00				580.1	
4+00				569.56	
6+00				602.41	
8+00				582.1	
10+00				550.1	
12+00				493.1	
14+00				437.73	
16+00				449.79	

(b) From 11th ave. to 4th ave.

	1937	1956	1970	1976	1980
46+00		414.11		638.53	
48+00		370.72		551.62	
50+00		524.03		506.04	
52+00		470.16		506.4	
54+00		412.37		427.53	
56+00		391.48		404.45	
58+00		371.91		400.26	
60+00		455.19		449.83	
62+00		419.5		445.4	
64+00		412.54		454.27	
66+00		458.16		461.4	
68+00		435.33		452.97	
70+00		521.54		488.37	
72+00		476.18		467.88	
74+00		444.76		448.47	
76+00		465.59		449.56	
78+00	421.83	425.04	481.07	425.84	
80+00	381.65	443.31	434.45	438.04	457.99
82+00	390.2	373.14	392.54	409.19	413.6
84+00	356.99	330.19	417.44	376.27	386.29
86+00	324.66	372.58	367.64	370.55	384.17
88+00	274.22	297.58	310.16	323.66	324.29
90+00	255.75	235.37	280.03	290.08	284.18
92+00	205.94	227.3	221.73	252.94	253.64
94+00	218.82	217.2	247.19	260.32	261.5

(c) From Norfolk ave. to Atlans ave.

	1937	1956	1970	1976	1980
177+18	271.37		343.79	334.12	341.48
179+07	261.35		313.08	303.37	303.78
181+17	284.96		298.39	299.09	291.25
183+27	275.92		291.22	295.1	300.03
185+37	291.11			292.49	
187+47	305.31			296.95	
189+79	309.97	305.79		317.57	

Table 17 Shoreline positions at 180 ft intervals for Station 328 + 67 to 379 + 09 from aerial photographic data, 1937, 1956, 1970, 1976 and 1980 near Little Creek Inlet

Shoreline position (Aerial photograph, 1937-1980)

	New Station	1937	1956	1970	1976	1980
1	328+67	537.16	478.05	486.9	484.63	497.49
2	330+47	508.57	463.54	475.89	470.84	457.2
3	332+27	511.53	443.58	470.41	447.49	470.19
4	334+07	495.07	443.4	445.87	438.95	430.64
5	335+87	498.47		440.67	421.85	420.84
6	337+67	494.05		432.27	412.3	414.54
7	339+47	478		427.06	388.93	379.93
8	341+27	435.96		409.71	393.39	345.25
9	343+07	447.56		407.46	356.67	333.97
10	344+87	432.71		391.9	356.92	323.67
11	346+67	419.7		361.2	339.14	320.58
12	348+47	390.16		355.47	325.07	301.45
13	350+26	386.55		326.6	303.77	294.99
14	352+06	378.37		325	283.06	274.58
15	353+86	352.74		316.63	269.56	251.46
16	355+66	346.27		300.76	264.05	296.09
17	357+46	333.34		310.4	262.45	272.7
18	359+26	309.59		292.3	240.07	253.35
19	361+06	302.82		286.97	233.16	258.23
20	362+86			277.99	237.98	245.48
21	364+67			278.61	217.59	238.03
22	366+49			291.79	205.4	227.03
23	368+29			287.52	214.05	234.35
24	370+09			298.56	217.13	251.36
25	371+89			296.51	233.02	236.19
26	373+69			301.74	240.32	250.57
27	375+49			315.97	245.51	261.43
28	377+29			348.85	296.84	312.01
29	379+09			391.2	383.25	391.85

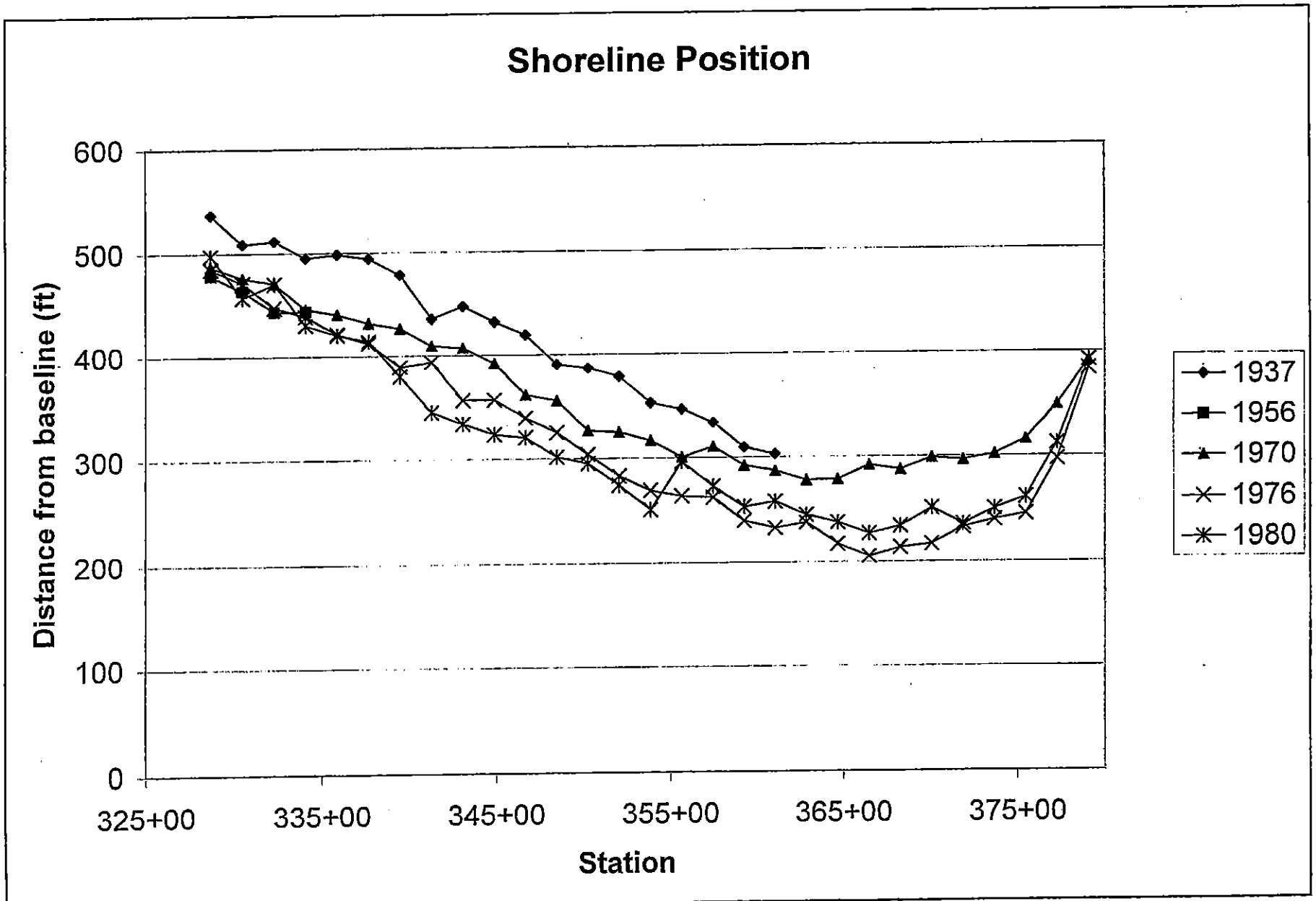

Figure 17 Shoreline positions at 180 ft intervals for Stations 328 + 67 to 379 + 09 from aerial photographic data, 1937, 1956, 1970, 1976, and 1980 near Little Creek Inlet

Table 18 Shoreline change rates at 1000 ft intervals for Station 80 + 00 to 328 + 00 (some missing) from aerial photographic data

Shoreline position change rate (fr/yr, 1000ft)

	1937-1956	1956-1970	1970-1976	1976-1980	1937-1980
0+00					
10+00					
20+00					
30+00					
40+00					
50+00					
60+00					
70+00					
80+00	3.25	-0.63	0.60	4.99	1.78
90+00	-1.07	3.19	1.68	-1.47	0.66
100+00	1.01	0.69	-0.02	2.68	0.92
110+00	-1.50	3.66	0.69	-1.36	0.50
120+00			-1.53	2.81	-0.29
130+00			4.14	1.60	0.98
140+00			1.04	2.13	1.09
150+00			0.74	0.56	1.57
160+00			2.73	-2.77	2.01
170+00			2.83	-3.40	1.80
180+00			-1.98	1.02	0.83
190+00	-0.20				
200+00	0.34				
210+00	-0.73			3.24	1.38
220+00	-3.27	1.95	1.57	13.12	0.63
230+00	-2.78	2.79	3.08	7.36	0.80
240+00	-2.69	1.63	3.82	4.76	0.32
250+00	-2.93	1.66	2.23	7.53	0.26
260+00	-2.42	1.36	-0.18	11.73	0.44
270+00	-2.27	-1.15	1.95	4.73	-0.67
280+00	-1.79	-0.60	4.36	0.86	-0.30
290+00	-3.55	-0.06	4.30	-2.29	-1.20
300+00	-3.72	0.62	2.92	-0.53	-1.09
310+00	-4.15	1.81	2.78	-0.29	-0.88
320+00	-1.45	0.09	-1.66	2.32	-0.63
328+00	-3.15	0.07	0.18	2.52	-1.11

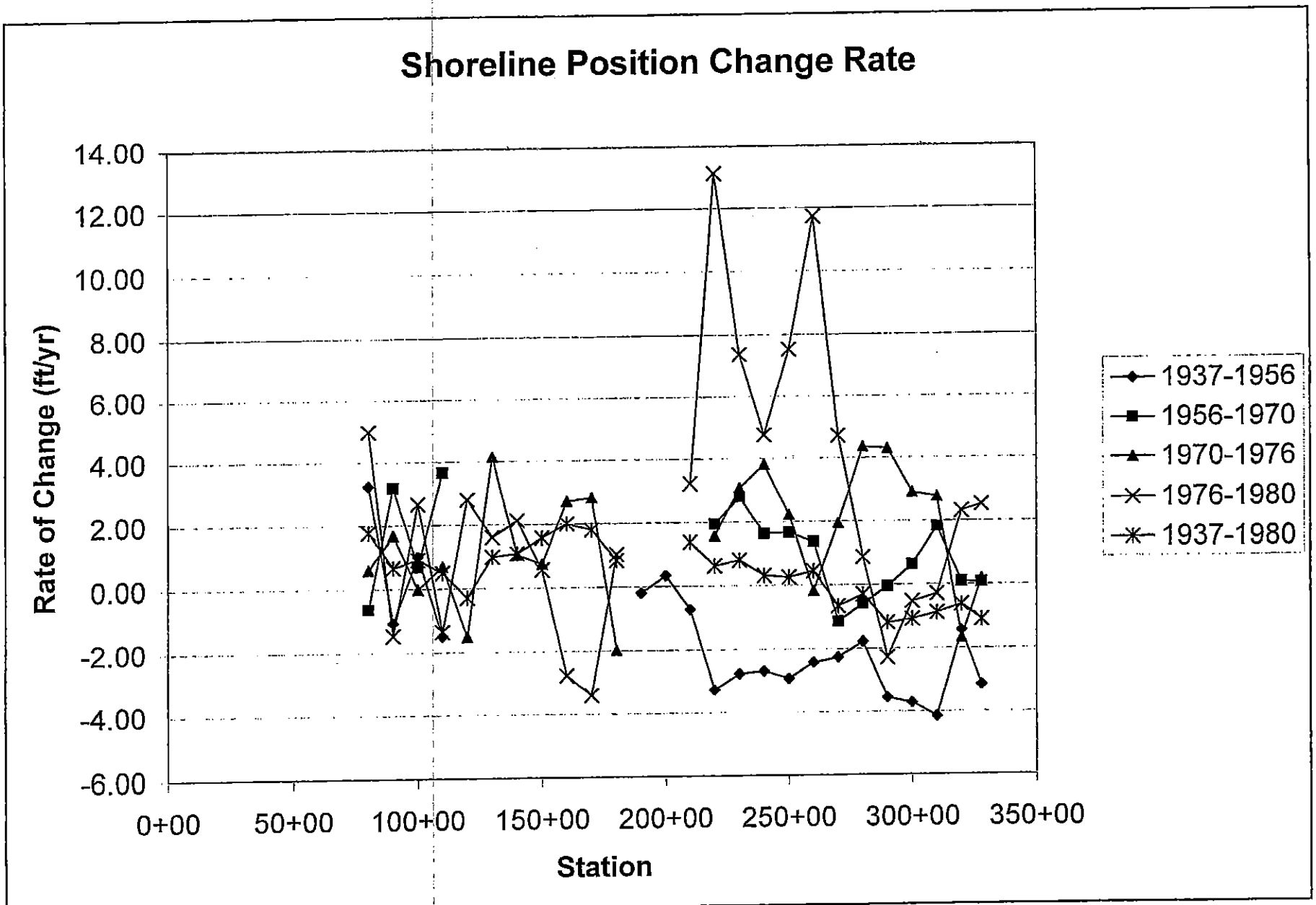

Figure 18 Shoreline change rates at 1000 ft intervals for Stations 80 + 00 to 328 + 00 from aerial photographic data

+ 00 at a much larger, average erosion rate of –2.31 ft/yr. The first beach nourishment occurred in 1953 near Little Creek Inlet (Table 3).

A limited range of more detailed change rate information is summarized in Table 19(a) and Figure 19 for Station 78 + 00 to 94 + 00 and in Table 19(b) and Figure 20 for Station 177 + 18 to 189 + 79.

The negative change rates near Little Creek Inlet for the 44-year interval (1937- 1980) are tabulated and graphically illustrated in Table 20 and Figure 21, respectively. The average was –1.79 ft/yr. Note that for the seven-year period, 1970-1976, the erosion rate was severe, averaging –6.71 ft/yr with the highest value of –14.4. ft/yr at Station 366 + 49.

5.3 Shoreline Position and Change Rates (1995 – 2002)

Extension of the terminal groin and construction of the two nearshore breakwaters took place in 1990. These coastal works have significantly altered the western end of the shoreline near Willoughby Spit.

5.3.1 Shoreline Positions

Table 21 presents all the results of shoreline positions from Willoughby Spit (0 + 00) to 21st Bay Street (328 + 00) and also more detailed data at three other locations. Figure 22 displays the trends for 1995, 1999, and 2002.

For the one-mile shoreline near Little Creek Inlet, Table 22 summarizes the data, Figure 23 shows the shoreline locations (color), and Figure 24 graphically displays the shoreline position trends for 1995, 1999, and 2002.

5.3.2 Change Rates

Change rates for the one-mile shoreline west of Little Creek Inlet are computed in Table 23 and plotted in Figure 25. They vary considerably from + 21.8 ft/yr (1999-2002) to minus 20.1 ft/yr (1995-1999), at Station 348 + 47 (32+42.51) and reflect construction of the nearshore breakwaters in August 2000 and November 2001 (see Section 2).

The change rates for the seven-year period 1995-2002 have not been calculated for this report. The short time interval and construction of coastal works make this data less useful for general trends analysis.

Table 19 Shoreline change rates at 200 ft intervals for (a) Station 78 + 00 to 94 + 00 and (b) 177 + 18 to 189 + 79 from aerial photographic data

From 11th st. to 6th st.

	1937-1956	1956-1970	1970-1976	1976-1980	1937-1980
46+00					
48+00					
50+00					
52+00					
54+00					
56+00					
58+00					
60+00					
62+00					
64+00					
66+00					
68+00					
70+00					
72+00					
74+00					
76+00					
78+00	0.17	4.00	-9.21		
80+00	3.25	-0.63	0.60	4.99	1.78
82+00	-0.90	1.39	2.78	1.10	0.54
84+00	-1.41	6.23	-6.86	2.51	0.68
86+00	2.52	-0.35	0.49	3.41	1.38
88+00	1.23	0.90	2.25	0.16	1.16
90+00	-1.07	3.19	1.68	-1.47	0.66
92+00	1.12	-0.40	5.20	0.17	1.11
94+00	-0.09	2.14	2.19	0.30	0.99

From Chesapeake Blvd. To Atlans ave.

	1937-1956	1956-1970	1970-1976	1976-1980	1937-1980	1937-1976
177+18			-1.61	1.84	1.63	1.61
179+07			-1.62	0.10	0.99	1.08
181+17			0.12	-1.96	0.15	0.36
183+27			0.65	1.23	0.56	0.49
185+37						0.04
187+47						-0.21
189+79	-0.22					0.19

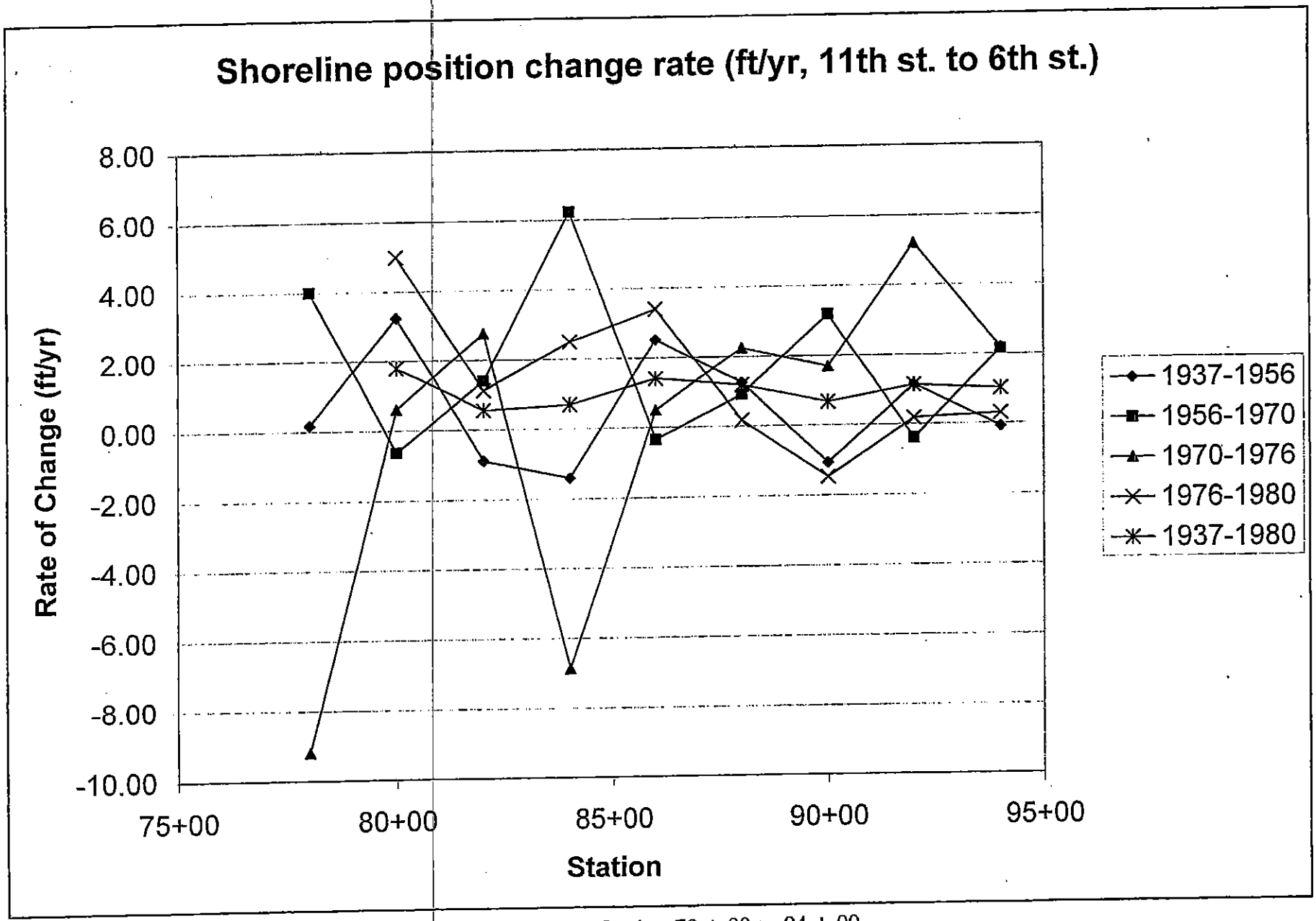

Figure 19 Shoreline change rates at 200 ft intervals for Station 78 + 00 to 94 + 00 from aerial photographic data

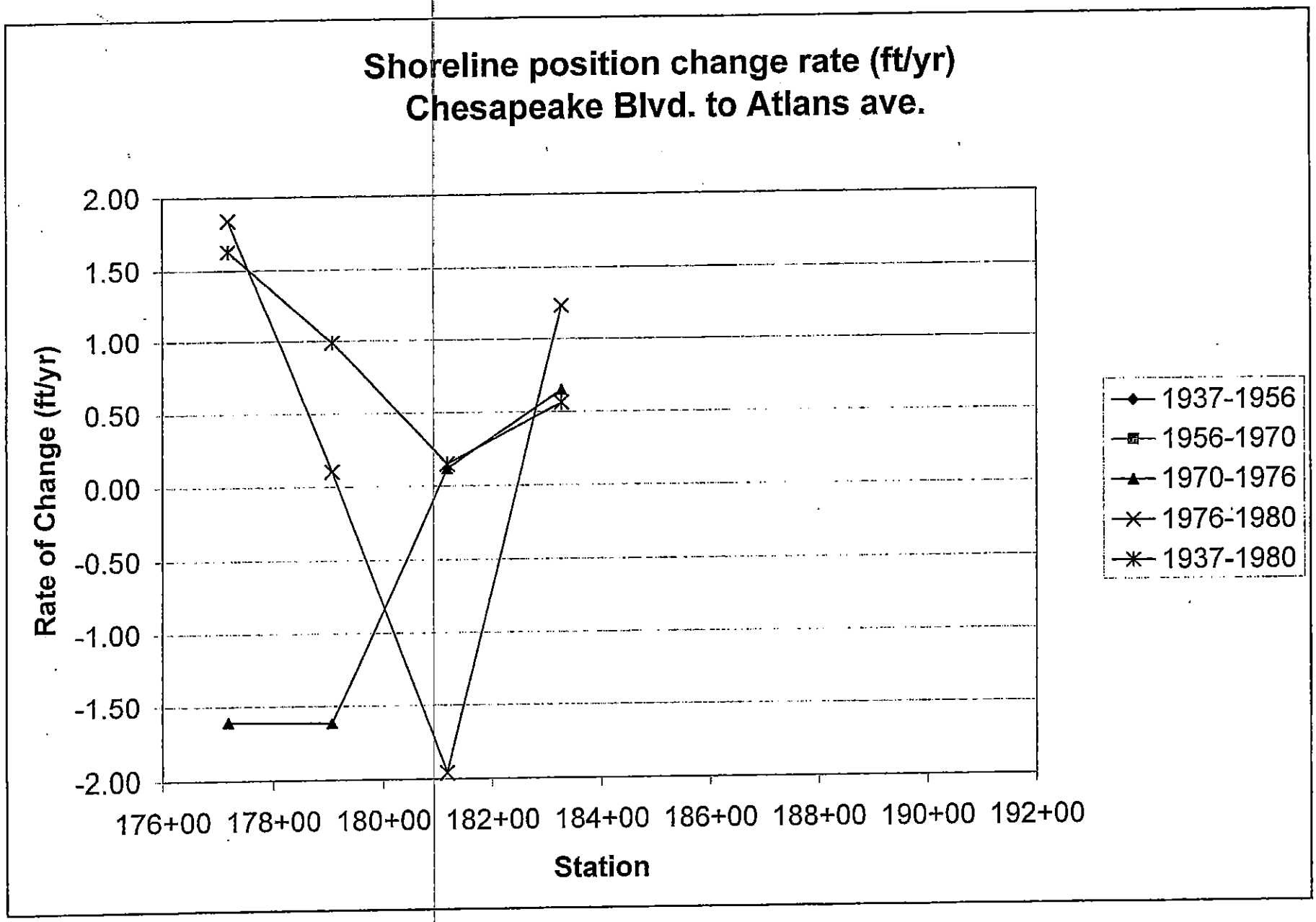

Figure 20 Shoreline change rates at 200 ft intervals for Station 177 + 18 to 189 + 79 from aerial photographic data

Table 20 Shoreline change rates at 180 ft intervals for Station 328 + 67 to 379 + 09 from aerial photographic data near Little Creek Inlet

Shoreline position rate (Aerial photograph, 1937-1980)

Position	New Station	1937-1956	1956-1970	1970-1976	1976-1980	1937-1980
1	328+67	-3.11	0.63	-0.38	3.22	-0.92
2	330+47	-2.37	0.88	-0.84	-3.41	-1.19
3	332+27	-3.58	1.92	-3.82	5.68	-0.96
4	334+07	-2.72	0.18	-1.15	-2.08	-1.50
5	335+87			-3.14	-0.25	-1.81
6	337+67			-3.33	0.56	-1.85
7	339+47			-6.36	-2.25	-2.28
8	341+27			-2.72	-12.04	-2.11
9	343+07			-8.46	-5.68	-2.64
10	344+87			-5.83	-8.31	-2.54
11	346+67			-3.68	-4.64	-2.31
12	348+47			-5.07	-5.91	-2.06
13	350+26			-3.81	-2.19	-2.13
14	352+06			-6.99	-2.12	-2.41
15	353+86			-7.85	-4.53	-2.36
16	355+66			-6.12	8.01	-1.17
17	357+46			-7.99	2.56	-1.41
18	359+26			-8.71	3.32	-1.31
19	361+06			-8.97	6.27	-1.04
20	362+86			-6.67	1.88	
21	364+67			-10.17	5.11	
22	366+49			-14.40	5.41	
23	368+29			-12.25	5.08	
24	370+09			-13.57	8.56	
25	371+89			-10.58	0.79	
26	373+69			-10.24	2.56	
27	375+49			-11.74	3.98	
28	377+29			-8.67	3.79	
29	379+09			-1.33	2.15	

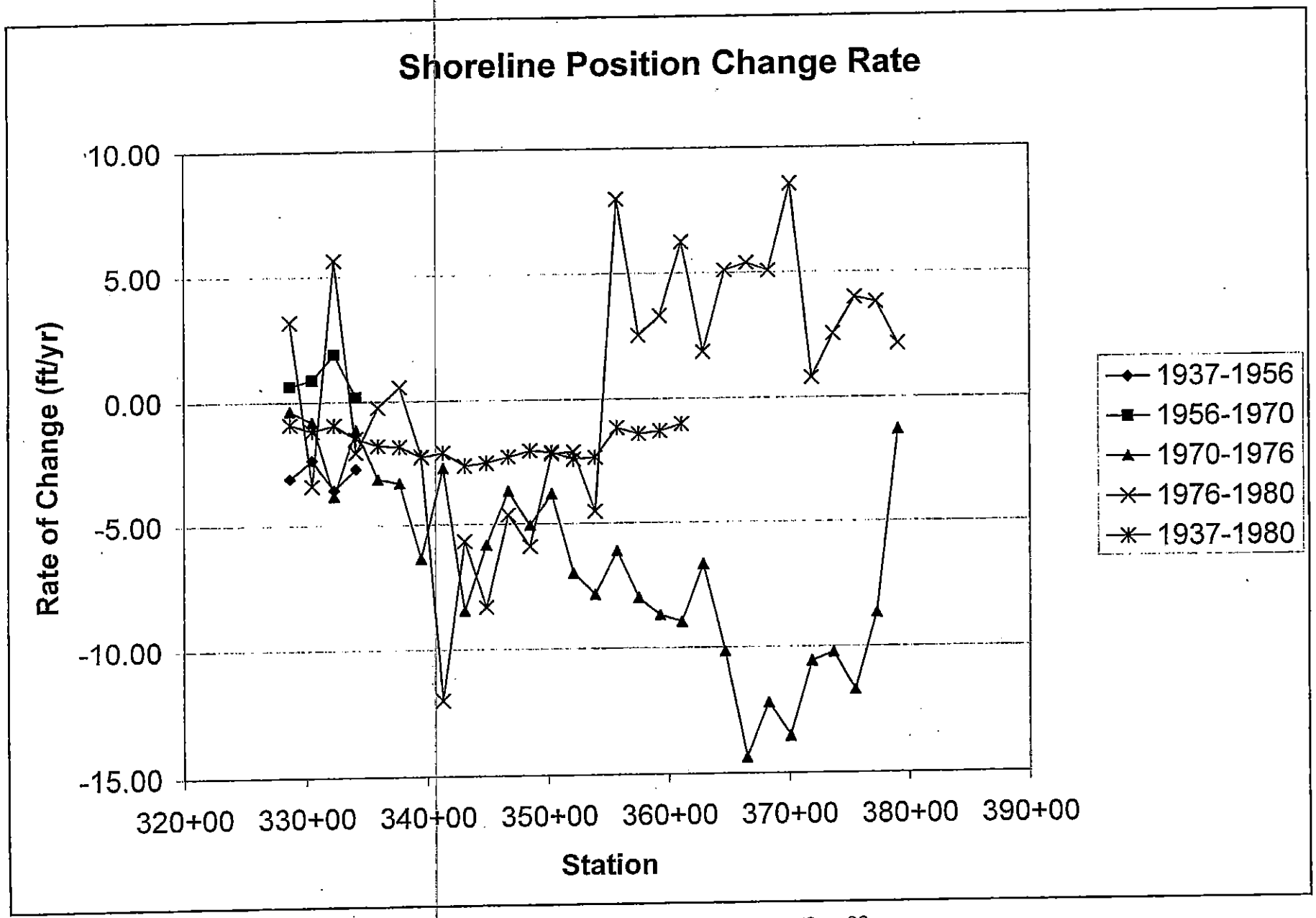

Figure 21 Shoreline change rates at 180 ft intervals for Station 328 + 67 to 379 + 09 from aerial photographic data near Little Creek Inlet

Shoreline Position (ft)

1000ft

	1995	1999	2002
0+00	709.4	795.4	836.3
10+00	858.6	825.6	850.9
20+00	511.2	484.6	
30+00	544.5	598.1	
40+00	657.8	594.3	
50+00	549.2	518.8	535.3
60+00	427.3	414.4	417.0
70+00	457.6	469.6	436.8
80+00	425.8	386.7	438.5
90+00	247.6	287.9	265.1
100+00	319.0	281.6	306.4
110+00	291.1	354.4	338.4
120+00	278.5	308.0	257.7
130+00	283.6	263.0	319.1
140+00	308.6	291.4	330.6
150+00	320.9	311.6	307.6
160+00	332.6	308.4	322.9
170+00	302.5	291.8	292.6
180+00	309.7	293.0	278.7
190+00	319.3	308.0	380.0
200+00	371.3	371.4	392.9
210+00	387.9	425.7	407.5
220+00	418.6		443.4
230+00	372.5		433.3
240+00	447.1		442.0
250+00	397.4	380.2	408.0
260+00	365.6		402.2
270+00	444.9		486.7
280+00	456.8	426.9	472.7
290+00	462.5	452.2	495.5
300+00	471.1	436.0	465.0
310+00	480.9	461.2	424.2
320+00	522.4	507.0	466.6
328+00	483.0	461.7	476.4

Terminal groin

	1995	1999	2002
0+00	709.4	795.4	836.3
2+00	666.1	706.8	771.7
4+00	750.8	703.3	749.0
6+00	850.9	815.9	841.5
8+00	877.8	780.0	810.3
10+00	858.6	825.6	850.9
12+00	812.4	781.6	808.6
14+00	770.0	675.5	695.1
16+00	673.8	580.7	586.5

11th to 4th

	1995	1999	2002
46+00	699.8	656.0	641.6
48+00	621.2	511.0	612.8
50+00	549.2	518.8	535.3
52+00	486.7	510.9	546.5
54+00	412.9	419.8	425.1
56+00	379.0	381.5	384.6
58+00	379.0	437.6	441.2
60+00	427.3	414.4	417.0
62+00	401.3	468.6	444.3
64+00	458.1	395.0	428.5
66+00	443.2	499.6	466.5
68+00	458.1	449.2	416.2
70+00	457.6	469.6	436.8
72+00	427.6	431.5	399.0
74+00	405.1	447.2	455.6
76+00	435.1	376.9	377.2
78+00	427.7	382.8	403.8
80+00	425.8	386.7	438.5
82+00	378.9	349.6	388.1
84+00	339.8	378.9	330.6
86+00	371.4	366.8	397.7
88+00	290.2	341.2	321.4
90+00	247.6	287.9	265.1
92+00	258.9	276.1	269.2
94+00	251.4	299.7	269.2

Chesapeake Blvd. To Atlans ave.

	1995	1999	2002
177+18	302.3	323.4	372.3
179+07	309.7	312.0	296.7
181+17	320.9	315.8	270.8
183+27	298.5	289.2	268.8
185+37	283.4	289.8	336.5
187+47	301.3	279.0	308.6
189+79	319.7	300.7	372.1

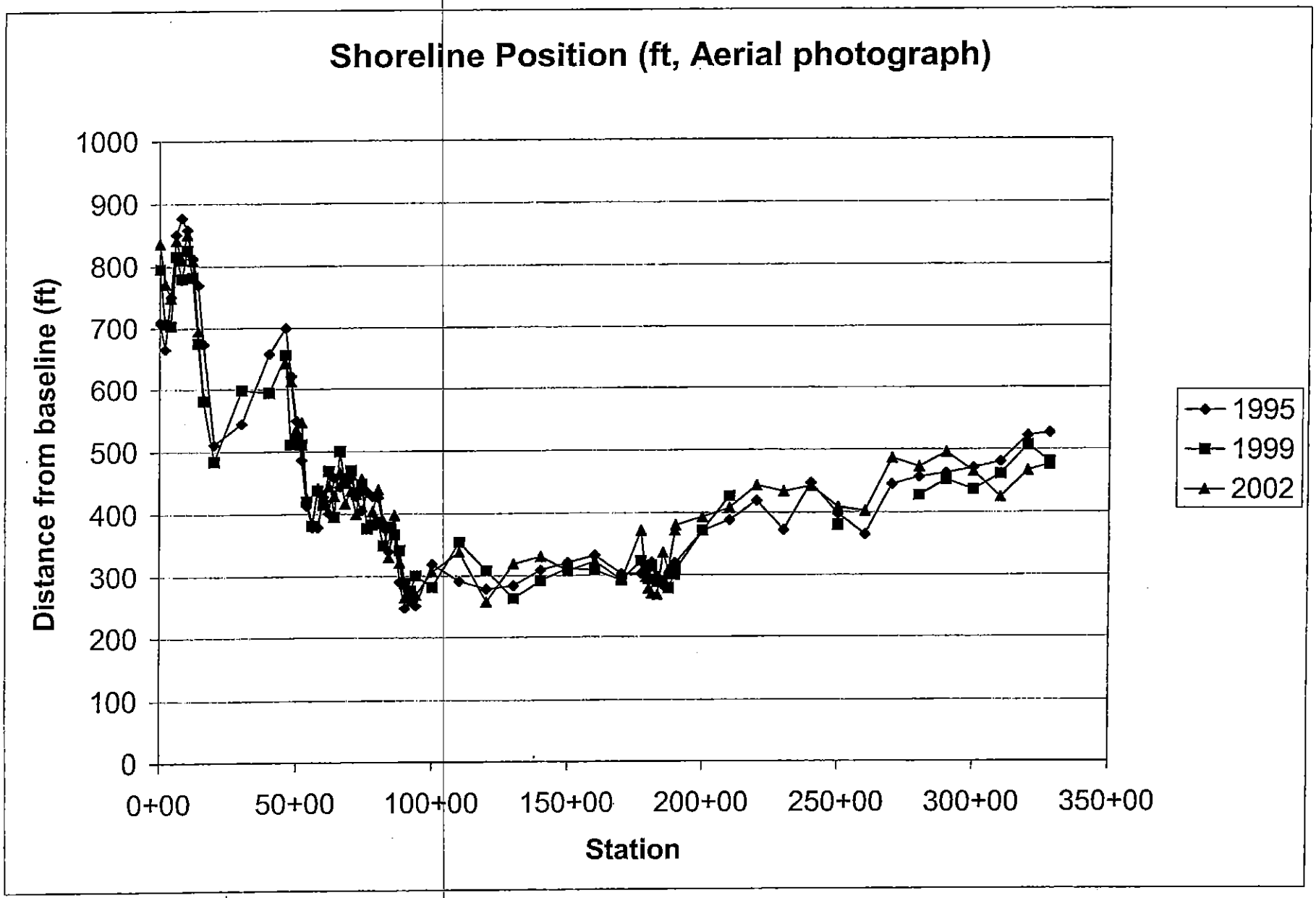
Shoreline Position (ft, Aerial photograph)
Distance from baseline (ft)
1000
900
800
700
600
500
400
300
200
100
0
0+00
50+00
100+00
150+00
200+00
250+00
300+00
350+00
Station
1995
1999
2002

Table 22 Shoreline positions at 180 ft intervals from aerial photographs, 1995, 1999, 2002 near Little Creek Inlet

Shoreline Positions at the West Side of Little Creek Inlet (ft)

Position	Station	1995	1999	2002
1	52+22.26	482.1	453.8	461.0
2	50+42.26	481.4	432.3	429.7
3	48+62.27	478.5	418.2	405.4
4	46+82.27	483.8	420.2	396.9
5	45+02.28	453.8	395.1	360.0
6	43+22.28	417.1	372.6	324.7
7	41+42.28	383.6	340.1	318.3
8	39+62.28	351.7	302.3	327.8
9	37+82.28	342.8	288.1	331.2
10	36+02.27	355.3	295.8	341.1
11	34+22.39	348.2	278.7	333.4
12	32+42.51	337.8	257.5	322.8
13	30+62.63	320.7	256.7	309.7
14	28+82.75	302.5	258.8	296.1
15	27+02.87	294.9	273.9	280.9
16	25+22.99	287.5	288.9	265.8
17	23+43.11	282.5	263.4	255.2
18	21+63.23	277.3	241.2	245.9
19	19+83.35	270.8	242.0	245.9
20	18+03.47	264.1	240.8	244.2
21	16+21.63	256.7	232.5	236.0
22	14+39.78	256.1	226.0	224.9
23	12+59.88	258.7	220.6	212.9
24	10+80.15	262.9	223.6	209.7
25	9+00.08	267.7	229.9	210.8
26	7+20.01	272.5	237.6	203.0
27	5+40.27	277.3	246.0	218.8
28	3+60.37	311.3	286.7	273.8
29	1+80.47	384.3	358.0	345.3

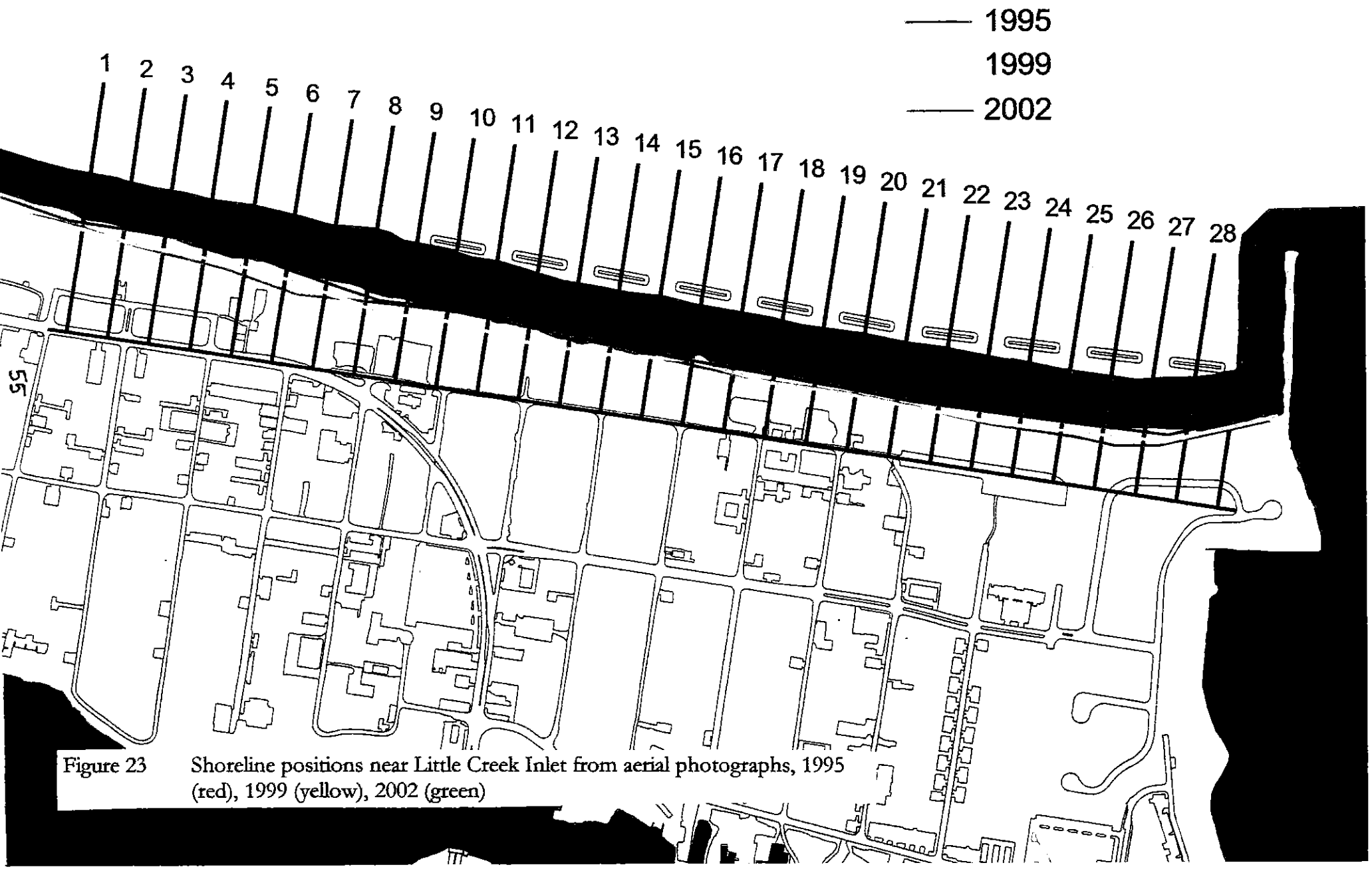

Figure 23 Shoreline positions near Little Creek Inlet from aerial photographs, 1995 (red), 1999 (yellow), 2002 (green)

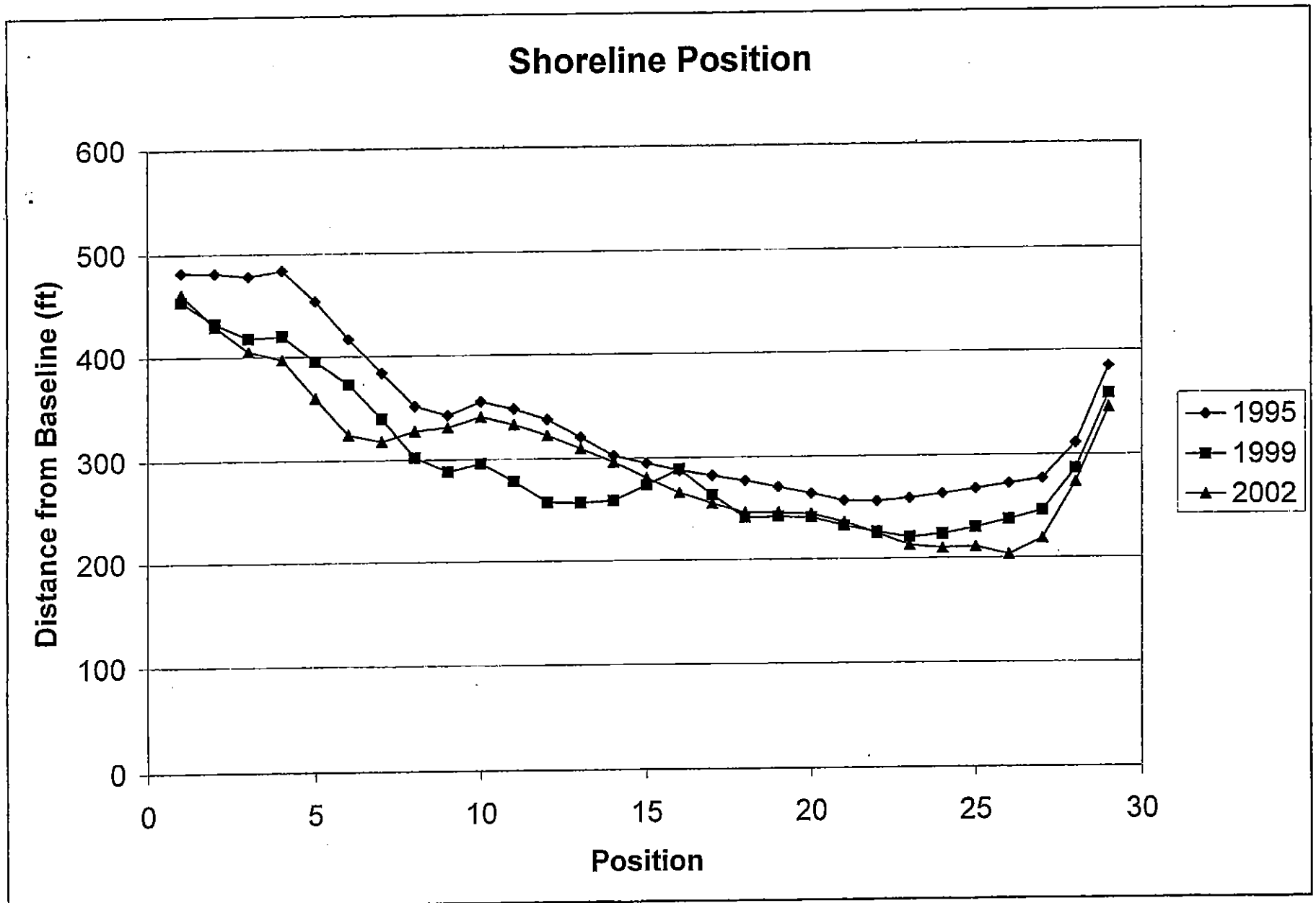

Figure 24 Trends in shoreline positions near Little Creek Inlet from aerial photographs, 1995, 1999, 2002

Table 23 Shoreline change rates near Little Creek Inlet from aerial photographic data, 1995, 1999, 2002

Shoreline Position Change Rate at the West Side of Little Creek Inlet (ft/yr)

Position	Station	1995-1999	1999-2002	1995-2002
1	52+22.26	-7.1	2.4	-3.0
2	50+42.26	-12.3	-0.9	-7.4
3	48+62.27	-15.1	-4.3	-10.4
4	46+82.27	-15.9	-7.8	-12.4
5	45+02.28	-14.7	-11.7	-13.4
6	43+22.28	-11.1	-16.0	-13.2
7	41+42.28	-10.9	-7.3	-9.3
8	39+62.28	-12.4	8.5	-3.4
9	37+82.28	-13.7	14.4	-1.7
10	36+02.27	-14.9	15.1	-2.0
11	34+22.39	-17.4	18.2	-2.1
12	32+42.51	-20.1	21.8	-2.1
13	30+62.63	-16.0	17.7	-1.6
14	28+82.75	-10.9	12.4	-0.9
15	27+02.87	-5.3	2.3	-2.0
16	25+22.99	0.3	-7.7	-3.1
17	23+43.11	-4.8	-2.7	-3.9
18	21+63.23	-9.0	1.6	-4.5
19	19+83.35	-7.2	1.3	-3.6
20	18+03.47	-5.8	1.1	-2.8
21	16+21.63	-6.1	1.2	-3.0
22	14+39.78	-7.5	-0.4	-4.5
23	12+59.88	-9.5	-2.6	-6.5
24	10+80.15	-9.8	-4.6	-7.6
25	9+00.08	-9.5	-6.4	-8.1
26	7+20.01	-8.7	-11.5	-9.9
27	5+40.27	-7.8	-9.1	-8.4
28	3+60.37	-6.2	-4.3	-5.4
29	1+80.47	-6.6	-4.2	-5.6
Average		-10.2	0.6	-5.6

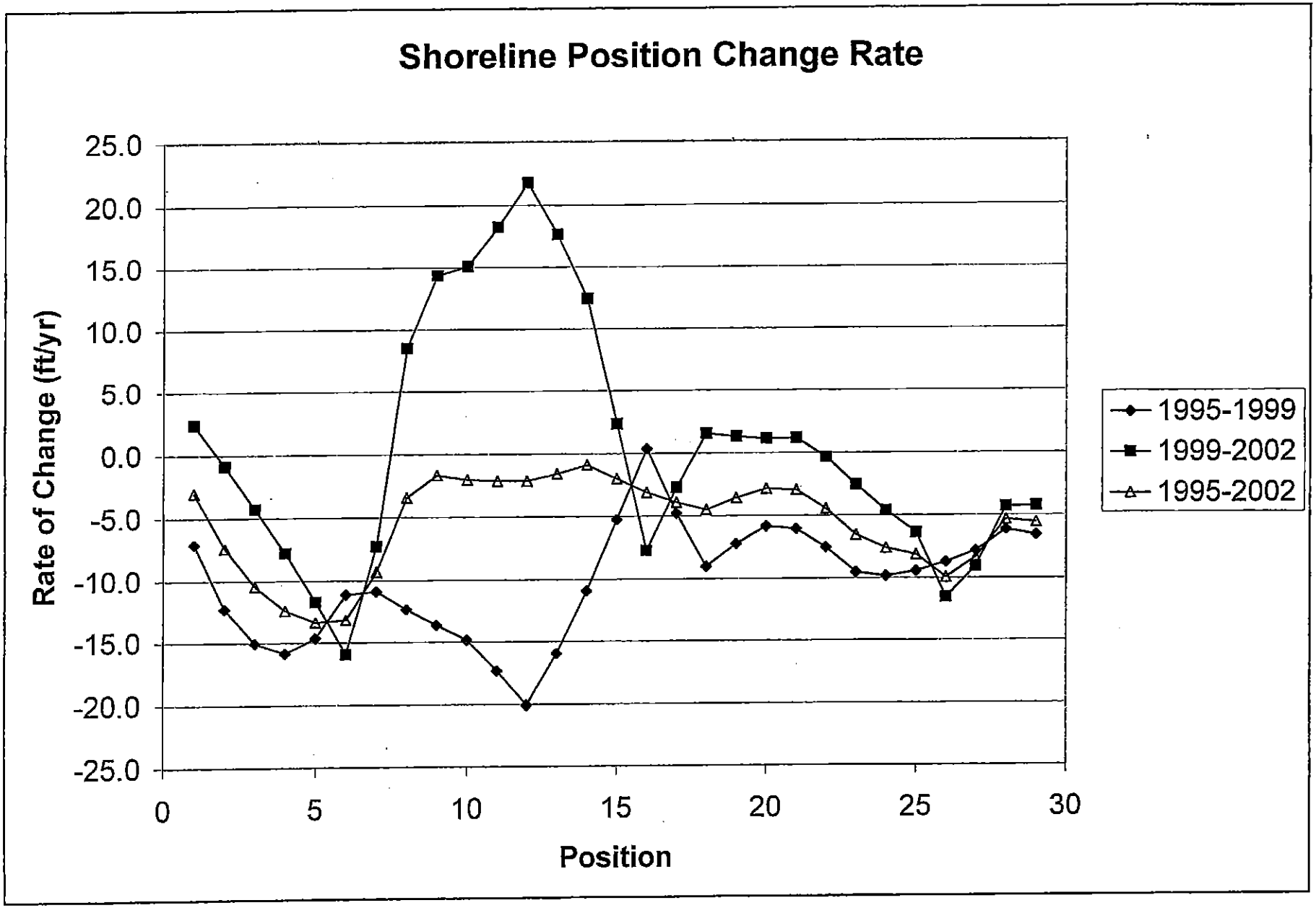

Figure 25 Trends in shoreline change rates near Little Creek Inlet from aerial photographic data, 1995, 1999, 2002

Section 6
Discussion of Results

6.1 Prior to Little Creek Inlet Jetties

For 65 years prior to construction of the jetties at Little Creek Inlet in 1926-1928, the shoreline was stable to slightly accretionary. For one mile west of the inlet, the accretion rate was about + 1.8 ft/yr. Further west, for a distance of 3.2 miles the accretion rate was + 0.4 ft/yr. No data exists for 1852 for the 3.0 miles further west to Willoughby Spit, so that no rates could be established.

6.2 After Jetty Construction

Major disruption of the coastal sediment transport process west of the inlet took place immediately following jetty construction. For a 14-year period (1916-1924), the erosion rate one mile west of the jetties was –10.9 ft/yr. For the next 14 years (1929-1942) a similar, average erosion rate of –10.3 ft/yr took place. For 1.3 miles further west, the average erosion rates were –4.4. ft/yr for the initial 14 years (1916-1929) and –3.8 ft/yr for the next 14-year period (1929-1942). Again, no data exists for 1929 from Station 260 + 00 to Willoughby Spit (4.9 miles) so that the erosion rate here cannot be determined for these two, 14-year periods.

6.3 Other Coastal Works

Groins constructed (private) after the jetties were built in the 1920's and then the 37 by the City of Norfolk in 1938 influence the 1942 map data and the first aerial photographed shoreline in 1937. These structures extend east to about Station 177 + 70 (Chesapeake Boulevard). Map data for 1942 begins at Station 150 + 00 so that the influence of the groins on the shoreline change rate for the 22 years from 1942 to 1963 cannot be determined, within the groin field to Willoughby Spit. However, the groin field also influences the shoreline eastward to Little Creek Inlet.

Beach nourishments in 1953 and 1960 west of Little Creek Inlet significantly influence the 1963 shoreline positions on the map data. For the 22-year period, 1942-1963, the shoreline accreted on average, + 8.1 ft/yr for one mile and + 9.2 ft/yr for another 3.2 miles west of the Little Creek jetties. These results are from the map data.

For a similar time frame, 20-year period, 1937-1956, using the aerial photographic record, the trend was negative (erosion) with an average value of –2.5 ft/yr from Station 190 + 00 to 334 + 07. The difference between the positive change rate map data (1942-1963) and the negative change rate aerial photographic results (1937-1956) may be due to (1) the photos taken at different times in the tidal cycle; (2) the influence of costal works (groins, beach nourishments); (3) the different starting and ending dates for the 20-year records; and (4) the missing photo data from Station 334 + 07 to the jetty.

For the 44-year period (1937-1980) the shoreline change rate was positive (+0.9 ft/yr) from Station 80 + 00 to 260 + 00 (3.4 miles) and negative (--1.1 ft/yr) from Station 260 + 00 to 361 + 06 (1.9 miles). No aerial photographic data was available near the terminal groin (0 + 00 to 70 + 00) and Little Creek jetty (361 + 06 to 380 + 89).

Shoreline positions and change rates are greatly influenced by major coastal construction efforts since 1980, namely, the elevated and lengthened terminal groin plus two nearshore breakwaters (1990); the "8-10th View Street" nearshore breakwater (1997-1998); the "Community Beach" nearshore breakwaters (1999); the "Little Creek Inlet" nearshore breakwaters (2000-2001) and the beach renourishment efforts in 1984, 1987, 1989, 1990, and later years (See Table 3). As a result, the 8-year photographic record (1995-2002) provides data that is useful for calibration of numerical models that include these structures, but no general trends have been discerned for this report.

Major beach nourishment projects between 1965 and 2002 (37 years) have placed over one million cubic yards of sand on Ocean Park Beach to the east in the City of Virginia Beach. This sand migrates west due to natural coastal sediment transport and inlet bypassing processes. Shoreline positions on all photographic records since 1965 include this material, to alter the shoreline location.

6.4 Other References

The Beach Management Plan, City of Norfolk (Andrews, Miller and Associates, 1993) summarized shoreline change rates as found in VIMS, 1976; Byrne and Anderson, 1977; Fleischer et al. 1977; and the Corps, 1983. Andrews, Miller and Associates, 1993 also made an analysis of shoreline changes between 1938 and 1992 to "....evaluate the effects of erosion control projects (i.e., coastal works) implemented by the City of Norfolk." In summary, the authors of the Beach Management Plan for the City concluded that "...taking into account the effects of the jetties at Little Creek Inlet, the erosion rate (for about 5,000 ft west of the inlet) is about –5.5 ft/yr with the remainder of the shoreline to Willoughby Spit eroding at a rate of -1.5 ft/yr" which is what was concluded by the Corps of Engineers (Corps, 1983). No information was provided in Andrews, Miller and Associates, 1993 as to how these shoreline change rates were determined.

Section 7
Summary Conclusions and Recommendations

7.1 Summary Conclusions

Table 24 summarizes the final shoreline change rate results for different periods in time and by different methods (map and aerial photos) for three "regions" with slightly variable boundaries that cover the 7.2-mile shoreline of interest. In general, for 65 years starting in 1852 this shoreline was stable to slightly accretionary. Jetty construction in 1926-1928 significantly interrupted the natural sediment transport processes and caused major erosion problems that continue to be felt today. Groin fields constructed in the late 1920's and 1930's, and maintained today; beach nourishments beginning in 1953 and continuing today; and the construction of an elevated and lengthened terminal groin together with nearshore breakwaters in the 1990's and early 2000's, have all helped to mitigate the erosion problem created by the jetties. Shoreline position and local, shoreline change rates are all influenced by these coastal works, the dates of the surveys, the survey methods, and the time intervals to estimate the rates.

Detailed shoreline position data as summarized in the tables, graphs, and CD-ROM (Appendix) should be useful to calibrate numerical models that calculate shoreline change with coastal structures present.

7.2 Recommendations

1. The locations and dimensions of all coastal engineering works (jetties, groins, nearshore breakwaters, beach renourishment projects, and seawall/bulkheads) should be determined in state plane coordinates and added to the City's AutoCADD drawings.
2. The shoreline position data resulting from this study should be archived in electronic format and made readily available to add to the City's AutoCADD drawings.
3. The beach profiles taken by the City of Norfolk, VIMS, and other researchers over the past 25 years should be organized, and placed in electronic format. The zero position should be found relative to the Baseline location and the profile location renamed to follow the Station numbering system along the Baseline as established in this report.
4. Beach profiles out to "depth of closure" should be routinely taken (a) before, (b) immediately after and (c) twice a year for all future beach nourishment projects.
5. The City of Norfolk should begin the routine collection of beach profile data over the 7.2 mile shoreline, archive this data, and use it to determine total volume changes over time to help manage the City's beaches.
6. The City of Norfolk should develop a new Beach Management Plan that reflects both the past 10 years of coastal works (since 1993 Plan) and the future plans of the City.

Table 24 Summary of shoreline change rates (ft/yr) for various time periods, by different survey methods, and for three, general stretches of the beach

Time Period	Shoreline Condition	Shoreline Change Rates, ft/yr		
		One Mile West of Inlet	Two to Five Miles ± West of Inlet	Three Miles ± to Willoughby Spit
1852-1916 (65 Yrs)	Natural (Before Jetty Construction)	+1.8	+0.4	No Data Available
1916-1929 (14 yrs)	Before/After Jetty Construction in 1926-1928	-10.9	-4.4	No Data Available
1929-1942 (14 yrs)	After Jetty Construction (Groins built in 1937-1938)	-10.3	-3.8	No Data Available
1942-1963 (22 yrs)	From Map Data	+8.1	+9.2	No Data Available
1937-1956 (20 yrs)	From Aerial Photographic Data	-2.5		See Table 18
1937-1980	From Aerial Photographic Data	-1.1	+0.9	See Table 18
1995-2002	From Aerial Photographic Data	Rates Highly Variable See Table 23	No Rates Calculated	

References

Andrews, Miller and Associates (1993). "Beach Management Plan, City of Norfolk, Virginia," Final Report, January, 71 p.

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Appendix A

Personal communication from Jim White, December 2003 regarding dates, locations,volumes,and lengths for beach nouishment projects 1995-2003.

Dec. 1995 - Approximately 34,000 cy 'backpassed' from the 15th View 'Willoughby Spit' shoreline and placed between 13th view and 12th View (4,000 cy in leeward pockets of approx. four groins), and between 8th View St. and 7th View St.(approx. 30,000 cy over a length of approx. 1000 ft) (Critical Area 1).

Dec. 1998 - 500 cy east of 8th view, near the site of the future groin spur. Length was 175 ft (Critical Area 1).

Dec. 1999 - 4000 cy of upland material placed near the center of the Central Ocean View breakwater project site (Critical Area 2). Length of project unknown.

Dec. 1999 - 1000 cy of sand 'backpassed' from 15th View St shoreline placed along approximately 200 ft of shoreline east of 8th View St (leeward of the newly constructed groin spur)(Critical Area 1).

Sept. 2001 - 2000 cy of sand 'backpassed' from the 15th View St shoreline and placed along approximately 300 ft of the shoreline east of 8th View St. (Between Breakwater 7 and the groin spur in critical area 1)(Critical Area 1).

May 2002 - 3438 cy of sand 'backpassed' from the 15th View St. shoreline and placed in the same location as the Sept. 2001 project.

Sept. 13, 2003 - 1100 cy of sand placed along 350 ft of shoreline, west of the 8th View St. beach access. The placement material was excavated from the 15th View Shoreline.

Oct. 2003 - 6000 cy of upland sand trucked in and placed along 545 ft of beach at 19th Bay St. in Critical Area 3 (in response to Hurricane Isabel)
Oct. 2003 - 1000 cy of upland sand trucked in and placed along 150 ft of beach just east of 30th Bay St. in Critical Area 3 (in response to Hurricane Isabel).

Dec. 2003 - 359,000 cy of sand placed along 1 mile of beach (Little Creek Inlet to 17th Bay St.) in Critical Area 3. The material used for this project was dredged from the Thimble Shoals Channel east of the Chesapeake Bay Bridge/Tunnel.

Dec. 2003 - 39,800 cy of sand placed along 1,260 ft of beach between 7th View (+400 ft) and 9th View St. in Critical Area 1.

Appendix B

CD-ROM with all data, calculations and plots as found in this report.